U. S. Department
of Transportation

**Federal Transit
Administration**

Intelligent Vehicle Initiative Needs Assessment

November 1999

FTA-TRI-11-99-33
DOT-VNTSC-FTA-

www.fta.dot.gov
www.volpe.dot.gov

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

Introduction

The U.S. Department of Transportation (DOT), through the Intelligent Transportation Systems (ITS) Joint Program Office (JPO), has embarked upon an Intelligent Vehicle Initiative (IVI) to accelerate the development and availability of advanced safety and information systems for a variety of vehicle types. Public transit, through the Federal Transit Administration (FTA), is an active participant in the IVI Program. While substantial transit benefits are anticipated through the application of IVI technologies, additional information was necessary to establish baseline transit needs, expected Transit IVI benefits, and Transit IVI research priorities. As recommended by the Transit IVI Steering Committee, this Needs Assessment was conducted to identify and prioritize transit industry requirements and problems with solutions involving IVI technologies.

Below, the main recommendations are provided, followed by a summary of the sections provided in the main report: needs assessment rationale, data sources and information gathering, FTA goals, issues of concern, technologies, and additional data requirements and operational tests.

Results of Needs Assessment and Preliminary Recommendations

According to the subsequent analysis, crash scenarios with the greatest risk and producing the most severity, are the highest priority candidates for IVI applications. The highest accident rate and severity rating accident is intersection type crashes in which the bus is struck by another vehicle. Prevention of intersection crashes is still in an evolutionary phase of technology development, and therefore receives a lower priority rating, but remains a high priority. The second major scenario is rear end type collisions in which the bus is struck by another vehicle. In addition to the risk and severity factors, these two types of crashes account for almost one third of the top five scenarios. In particular, it appears that the rear end and side struck type of crash is on the rise, as demonstrated by the trends of the past three years. Thus, lane change and rear end collision mitigation technologies are particularly appropriate priorities.

Mid level types of accidents, which carry a medium range of risk and severity, include the other half of the intersection type, in which the bus strikes another vehicle; rear end, in which the bus does the striking; and both backing up type crashes. These account for another 14% of all accidents within the top five. All except rear end collisions, in which the bus strikes another vehicle, have a low corrective action rate. Therefore, collision mitigation and tight maneuvering technologies are applicable and appropriate priorities.

Recommendation One: Prioritize Four User Services

Based on the data analysis and other factors described later, four user services have been identified for transit as high priority IVI user services. These services focus most particularly on the safety of the driver (and indirectly both passengers and pedestrians) and the vehicle in preventing accidents. Using systems that enable drivers to process information, make better decisions and operate vehicles more safely are the strong points of the following four priorities:

Lane Change and Merge Collision Avoidance
Forward Collision Avoidance
Rear Impact Collision Mitigation
Tight Maneuvering/Precise Docking

Recommendation Two: Collect Additional Transit-Specific Data

Even as this needs assessment analysis points to IVI technologies for transit, there remains a critical need for real life data gathering that is transit specific. In order to specifically evaluate the effectiveness of IVI technologies, the accident data needs to be more specific with respect to the accident characteristics, including causal factors. All transit IVI projects should require detailed accident analysis phases.

Needs Assessment Rationale

According to one study sponsored by the USDOT, which estimated the economic costs of motor vehicle accidents (all vehicles, not exclusive to transit buses), the largest single cost component is property damage, which accounted for over a third of total economic costs. In total, 22,919 bus related collisions cost the U.S. $395 million in 1997. Of equal or greater importance is the safety of the riding and pedestrian public. While transit fatalities are rare, any pedestrian or rider accident can and should be minimized. These IVI technologies will greatly enhance public safety, both by preventing accidents and minimizing property damage. A recommendation for the future would be an increased focus on pedestrian-specific IVI applications. These accidents have severe consequences and future efforts should be directed at them. Additionally, future IVI applications can be focused on minimizing the intersection crashes mentioned earlier. As the technology evolves, this priority will be realized with more advanced technological applications than are currently available.

The potential applications of IVI can help define transit's future. Some of the transit related IVI applications that have great potential to boost safety and efficiency include:

- An in-vehicle collision avoidance/warning system.
- An in-vehicle obstacle and pedestrian warning system.
- An in-vehicle passenger monitoring system.
- A real-time transit passenger information network that gives transit passengers and drivers real-time information about the transit network during their travel.

Data Sources and Information Gathering

A thorough search was conducted to identify and obtain relevant information and documentation on: transit industry problems and issues; relevant FTA goals; transit service and user demographic trends; existing levels of transit bus system safety and operating performance; potential Transit IVI applications, costs and benefits, and impacts; and related transit technology initiatives.

The data sources used in this report include: FTA National Transit Data Reporting System and the Safety Management Information System (SAMIS), the National Highway Traffic Safety

Administration General Estimates and Fatal Accident Reporting Systems, the Bureau of Transportation Statistics, the National Safety Council and a sample of actual transit system claims data. This was done to establish baseline statistics and to determine the needs of the Transit IVI program.

The National Automotive Sampling System (NASS) General Estimates Systems (GES) provided the most usable data about all types of crashes and related vehicle types. By restricting attention to police-reported crashes, the GES concentrates on those crashes of greatest concern to the safety community and the general public. While limited, this data provided the basis for the above recommendations.

The GES data was supplemented by direct transit industry input. Channels for input included the following: meetings on Transit IVI held in Houston in December 1997 and in Salt Lake City in February 1998; the Transit IVI Internal Platform Team, which is a small group of transportation professionals who offer technical support to the FTA; the Transit IVI Steering Committee which was established to provide formal input to the IVI Program through ITS America; and the results of the US DOT Request For Information.

Prior to this effort, the Steering Group had been discussing crash data based on individual transit systems and anecdotal data. A more systematic analysis of available transit data was required. As a result, a needs assessment, incorporating baseline statistics was conducted. As the data shows, the five most frequent crash types involving a motor coach are: lane change, rear end, intersection, parked, and backing up. The total for the top five crash categories comprises approximately 87% of crashes involving motor coaches within the United States, between 1994 and 1996, according to the GES data system. The needs assessment breaks down each crash category with a brief description, a narrative of the highlights of the in-depth analysis for the category, and finally gives a summary conclusion of implications relating to particular user service areas.

FTA Goals

The "FTA 5 Year Plan" identifies a number of transit goals for the next few years, as well as for the longer term. Several categories cover these goals, including passenger safety and security, equipment and infrastructure, and fleet operation programs. The overall strategic goal of Safety and Security is to "achieve the highest practical level of passenger safety and security in all modes of transit through training, technical assistance, innovation, and technology."

In conjunction with FTA goals, current transit needs relate to safety and security, normal driving, and system operations. For these same areas, future transit needs will be assessed based on projected changes in passenger and driver demographics, transit service type and performance requirements, and the operating environment in terms of traffic and road conditions.

Issues of Concern

In an effort to adjust to limited budgets, many transit systems find themselves cutting service and increasing fares regularly. The transit industry, with increasingly restricted funding, finds itself bearing the costs of expensive technologies and infrastructures necessary to support their systems. Transit managers cannot afford to be adventurous, either from a cost or operations standpoint, because there is minimal funding available for experimentation, and a system failure is unacceptable to the riders who rely on the service. There tends to be a reluctance to "be the first" or to be the testing ground in the public arena.

There is a perception in the transit industry that deployment of new technologies, especially those that are not the traditional cutting edge (information flow-oriented i.e., real-time fleet management and traveler information services) are high risk. Additionally, there is the critical need for acceptance from the unions in implementing technological changes that will affect their very jobs. Employee training coupled with a change in perception will be important and necessary steps in integration of IVI into transit fleets.

Lastly, the importance and uniqueness of the existing transit infrastructure must be recognized. Any deployment of new technologies should be synergistic with existing infrastructure, thus eliminating the need to create new infrastructure accouterments. And emphasis must be placed upon cost effectiveness and return of capital investment. This is a pivotal point for the determination of new and enhanced service provisions for transit providers.

Technology

A principle component of a collision avoidance system is the sensor to be used to detect the presence of an object. This critical piece of hardware must be chosen carefully so as to match the environment in which it is to be used. Various technologies exist, and are well understood, that lend themselves to use as a sensor in a collision avoidance system. Each has strengths and weaknesses, which make it more or less suitable for use in a given type of environment. In addition to a sensor, the IVI system will require a warning mechanism, and these two pieces put together form the technology behind IVI applications. More information on the strengths and weaknesses of each type of technology is discussed in detail in the body of the report.

Additional Data Requirements and Operational Testing

Even as the data analyses point to IVI technologies for transit, it is important to recognize that there remains a critical need for real life data gathering that is transit specific. The GES was a reasonable source, but it has various constraints that render it less than ideal.

As the performance specification projects commence, data collection is a critical piece of the testing scope. Baseline statistics proposed as benchmarks in measuring the effectiveness of the projects in these areas should include, but not be limited to: frequency and severity of accidents, injuries and fatalities, vehicle role, corrective action, movement prior to critical event, critical event, and damage costs. An effective benchmark would be a reduction in critical factors: overall incidents, injuries/fatalities, and costs. Further analysis of the data, such as location of damage, date and time, and geographical location, is suggested to assist in the placement of sensors in support of both the performance specification projects and any future operational tests.

CHAPTER 1: INTRODUCTION
Background

The U.S. Department of Transportation (DOT), through the Intelligent Transportation Systems (ITS) Joint Program Office (JPO), has embarked upon an Intelligent Vehicle Initiative (IVI) to accelerate the development and availability of advanced safety and information systems for a variety of vehicle types. The goal is to integrate driver assistance and user information functions to permit vehicles and fleets to operate more safely and efficiently. The IVI will include applications for private passenger vehicles, trucks, buses, and specialty vehicles. While much research and demonstration activity will be oriented to the four separate vehicle platforms, the IVI Program will foster cross-fertilization to maximize transportation benefits across all surface transportation modes.

Public transit, through the Federal Transit Administration (FTA), is an active participant in the IVI Program. While substantial transit benefits are anticipated through the application of IVI technologies, additional information is required to establish baseline transit needs, expected Transit IVI benefits, and Transit IVI research priorities. A synthesis of existing information and experience, coupled with a cross section of transit industry input, is needed to make the results of the Needs Assessment useful and relevant.

Objectives

This Needs Assessment identifies and prioritizes transit industry requirements, and problems, which lend themselves to solutions involving IVI technologies. It is limited to metropolitan area transit systems involving fixed route and paratransit/demand-responsive bus/van systems. This study was undertaken with the close involvement of the Internal Platform Transit IVI Team and Steering Committee, which were created to advise FTA and ITS America on Transit IVI activities.

Approach

The existing definitions of IVI Services (list of 26 defined in the IVI Request for Information - RFI) have been used as examples of potential IVI technology applications to communicate with the transit industry. Data on existing levels of transit safety and efficiency have been analyzed and used as a baseline from which to quantify needs, against which the potential benefits and impacts of candidate IVI Services can be considered. Transit industry input came from meetings on Transit IVI held in Houston in December 1997, and in Salt Lake City in February 1998; the Transit IVI Internal Platform Team; the Transit IVI Steering Committee, established to provide formal input to the IVI Program through ITS America; and the results of the U.S. DOT Request For Information. Surveys and focus groups, literature searches and research, as well as data analysis, were all utilized to ascertain the attitudes of a broad cross section of the transit industry.

Work Elements involved in the completion of the Transit IVI Needs Assessment included:

- Literature/Information Search - A thorough search was conducted to identify and obtain relevant information and documentation on: transit industry problems and issues; relevant FTA goals; transit service and user demographic trends; existing levels of transit bus system safety and operating performance; potential Transit IVI applications, costs, benefits, and impacts; and related transit technology initiatives such as Advanced Public Transportation Systems (APTS) and Bus Rapid Transit.

- Establish Baseline Transit Statistics - Statistics on bus vehicles and facilities, safety/security accidents/incidents, fleet operating performance, and customer service was documented and analyzed to establish a baseline against which Transit IVI applications can be proposed as strategies for improvement.

- Assess Current and Future Transit Needs - In conjunction with FTA goals, assess current transit needs related to safety and security, normal driving, and system operations. For these same areas, future transit needs has been assessed based on projected changes in passenger and driver demographics, transit service type and performance requirements, and the operating environment in terms of traffic and road conditions.

- Describe Applicable Transit IVI Services - IVI Services, such as those described in the RFI, were identified, described, and related to transit needs. Attempts were made to determine the availability of the service-related technologies, and their potential. In addition to the RFI, and the information obtained in the previous task, Department sponsored resources were included when applicable.

- Identify Transit IVI Impacts - The benefits, costs (when available) and other impacts of Transit IVI technology applications were identified (qualitatively, quantitatively if possible). The benefits were related to the transit needs as previously defined. Both positive and negative impacts and general cost parameters were described, if information was available. The relative potential of various Transit IVI technologies will be estimated by considering the impact of a single application and the magnitude of current or future applications which are possible among U.S. transit systems. Consideration was given to the potential benefits of Transit IVI applications that increase bus system performance (e.g., Bus Rapid Transit), and provide an economical alternative to constructing new fixed guideway rail systems.

- Assess Transit Industry Attitudes - A sampling was compiled of the transit industry to ascertain current and future needs, and the perceived value of Transit IVI applications in addressing them. The sampling included surveys and focus groups, and permitted a prioritization of needs and an estimation of the relative importance of potential Transit IVI applications for the U.S. transit industry.

- Prioritization of Transit IVI Applications for Development - Based on the outputs of the previous tasks, the Transit IVI applications worthy of further research and development under the Transit IVI Program were prioritized. Issues of concern, specific areas on which to concentrate, and additional studies required are identified.

- Draft Needs Assessment Report - The results of previous tasks were incorporated into a Draft Needs Assessment Report by the Volpe National Transportation Systems Center, and reviewed by the Steering Committee, and the U.S. DOT.

- Final Needs Assessment Report - Based on the comments received from the IVI Steering Committee, a Final Transit IVI Needs Assessment Report will be produced. It will serve as guidance to the FTA in developing its Transit IVI Research and Development Plan, and in justifying IVI Program funding.

CHAPTER 2: BASELINE TRANSIT STATISTICS

There are several sources of crash data available, but few that address crash scenarios at the level necessary for the purpose at hand. The data sources used in this report include: Federal Transit Administration National Transit Data Reporting System and the Safety Management Information System (SAMIS), the National Highway Traffic Safety Administration General Estimates (GES) and Fatal Accident Reporting Systems (FARS), the Bureau of Transportation Statistics, the National Safety Council and a sample of actual transit system claims data. This was done to establish baseline statistics and to determine the needs of the transit IVI program.

National Safety Council Data:

Calendar Year 1994

	Passenger Deaths	Passenger Miles in Billions	Deaths Per 100M Passenger Miles	1984-1996 Average Death Rate
Transit Buses	5	20.4	0.02	0.02
Intercity Buses	4	25.3	0.02	0.02

Intercity buses carried 343 million passengers and transit buses carried 5.5 billion passengers in 1994.

Calendar Year 1995

	Passenger Deaths	Passenger Miles in Billions	Deaths Per 100M Passenger Miles	1983-1995 Average Death Rate
Transit Buses	0	19	0	0.02
Intercity Buses	4	27.7	0.01	0.01

Intercity buses carried 359 million passengers and transit buses carried 5.1 billion passengers in 1995.

Calendar Year 1996

	Passenger Deaths	Passenger Miles in Billions	Deaths Per 100M Passenger Miles	1984-1996 Average Death Rate
Transit Buses	5	19	0.03	0.02
Intercity Buses	2	28.3	0.01	0.01

Intercity buses carried 360 million passengers and transit buses carried 5.0 billion passengers in 1996.

The average transit fatality rate (.02) is low compared to other modes of transportation. Average fatality rates for other modes are .94 (automobiles), .04 (railroad passenger trains); and .06 (scheduled airlines). According to the NSC data, passenger deaths and death rates for railroad passenger trains and scheduled airlines have risen over the past six years. By contrast, passenger deaths and death rates for buses have declined over the same period. Transit, by far, appears to be a much safer mode of transportation.

2.1 Safety Management Information Statistics

The Safety Management Information Statistics (SAMIS) is a compilation and analysis of mass transit accident, casualty, and crime statistics reported under the Federal Transit Administration's (FTA's) National Transit Database (NTD) Reporting System by FTA-funded transit systems in the United States. It is uniformly collected, comprehensive safety and security data from approximately 400 transit agencies throughout the country. The data is collected via FTA Form 405.

According to the SAMIS (Annual Reports for 1994 to 1996), incidents involving bus collisions with other vehicles, objects and people have all declined over the past four years.

Incidents	1994	1995	1996	1997
Collisions with Other Vehicles	37553	20801	20260	19947
Collisons with Objects	2767	2034	2177	2140
Collisons with People	1225	906	869	836
Totals	41545	23741	23306	22923

For the most part, fatalities for the same categories and period have remained constant, with a small increase in those incidents in which a fatality was the result of a collision with an object.

Fatalities	1994	1995	1996	1997
Collisions with Other Vehicles	47	118	44	46
Collisons with Objects	1	2	4	6
Collisons with People	49	37	36	49
Totals	97	157	84	101

According to the Bureau of Transportation Statistics, bus occupant fatalities in 1995 and 1996 (school, intercity and transit) accounted for less than 1% of transportation fatalities

There appears to be a small increase in the number of incidents in which bus collisions resulted in injuries. Although small, bus injuries are expensive in terms of both legitimate and fraudulent claims. Of particular interest here is that the injuries resulting from collisions with objects have almost doubled. In the cases of resulting fatalities, a rise also occurred in this category. This could be an indication of a need for obstacle/object detection.

Injuries	1994	1995	1996	1997
Collisions with Other Vehicles	17234	16325	19229	18502
Collisons with Objects	405	727	971	765
Collisons with People	1190	847	871	767
Totals	18829	17899	21071	20034

A closer look at bus injury figures reveals that if extraneous information, such as "slips, trips and falls" are extracted from the data, injuries, as a direct result of collisions, are on the decline. Yet, fatalities directly related to collisions are remaining fairly constant.

NOTE: These summary numbers do not equal the previous page totals, because they include additional off-bus incidents.

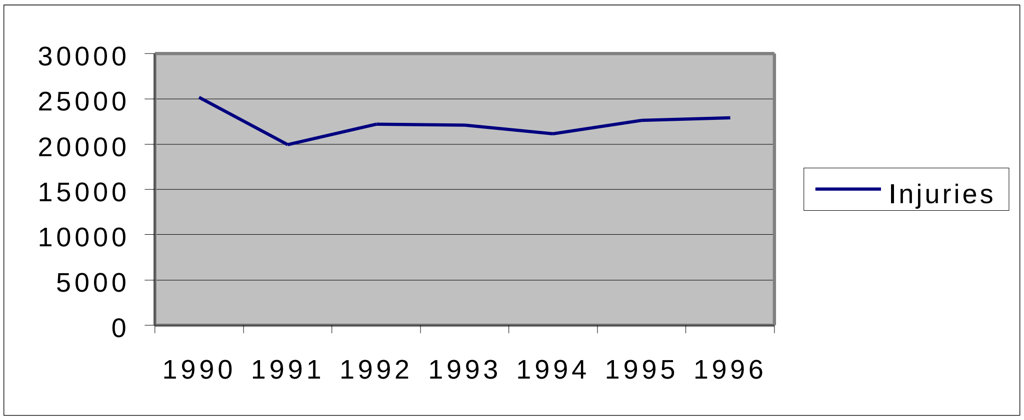
SAMIS (All types)

	1990	1991	1992	1993	1994	1995	1996	1997
Bus Incidents*	70437	63453	52482	45580	49185	42780	40456	40523
Bus Collisions**	55076	44350	34204	28491	27625	23733	23305	22919
Bus Injuries*	40006	38619	40090	38873	42195	41297	39709	39181
Bus Fatalities*	110	88	99	83	108	82	101	109
Bus Personal Casualties***	14853	18665	17895	16795	21072	18655	16774	17285
Bus Injuries Minus Personal Casualties***	25153	19954	22195	22078	21123	22642	22935	21896

*includes: collisions, derailments, personal casualties, and fires- does not equal previous page totals.
**includes: collisions with vehicles, objects, and people, excepts suicides -
***excludes: collisions, derailments and fires

It is critical to extract these other incidents from this data. Otherwise the data misrepresents those incidents that actually occurred as a result of collisions. A graphical representation of those incidents in which an injury was the result of a collision appears below, showing injuries remaining fairly constant.

Figure 1: BUS INJURIES MINUS PERSONAL CASUALTIES



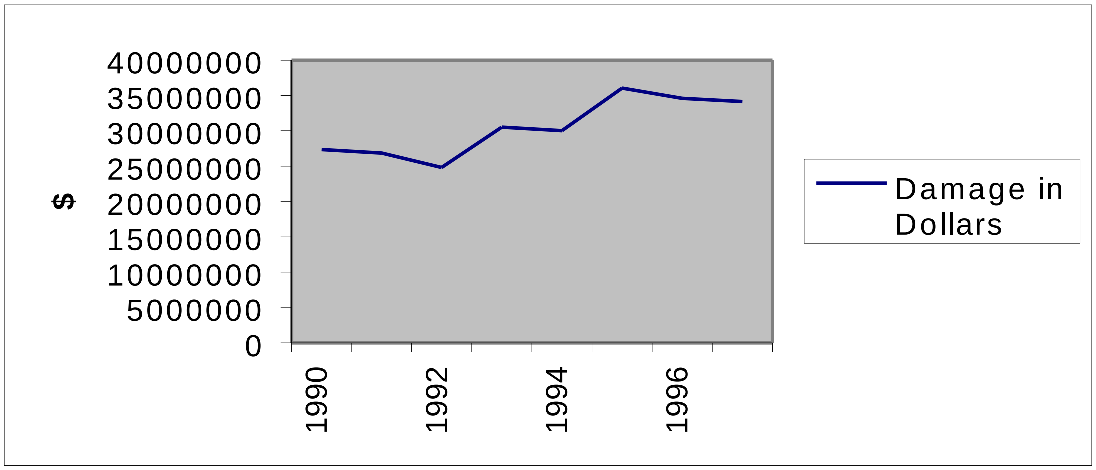
2.2 Property Damage of Bus Related Injuries (NTD)

Another indicator that must be examined in this type of analysis is that of property damage.

	1990	1991	1992	1993	1994	1995	1996	1997
LMB*	14,760,209	12,050,771	13,105,639	13,091,179	16,754,916	23,305,005	19,791,293	17,801,076
MMB*	9,343,884	11,238,640	8,900,792	9,440,339	9,490,771	9,474,456	11,475,827	12,795,432
SMB*	3,264,278	3,543,247	2,807,956	7,971,835	3,748,256	3,240,757	3,355,253	3,568,235
TOTAL	**27,368,371**	**26,832,658**	**24,814,387**	**30,503,353**	**29,993,943**	**36,020,218**	**34,622,373**	**34,164,743**

*SAMIS descriptions Large Motor Bus (LMB), Medium Motor Bus (MMB) and Small Motor Bus (SMB) describe the size of the transit agency which operates the bus, not the size of the vehicles (i.e., bus agency with > 500 vehicles = LMB; < 100 buses = SMB, <500 and >100 =MMB). Therefore, LMB, MMB and SMB are not true transit modes, but a representation of agency size.

Figure 2: PROPERTY DAMAGE --- BUS INCIDENTS



Data is provided only for transit systems that report safety data to the USDOT/FTA Safety Management Information Statistics (SAMIS) and does not cover directly operated urban transit systems. As mentioned earlier, only transit systems receiving FTA funding report their data.

Over a seven year period, property damage related to bus incidents rose overall by 25%. According to one study sponsored by the USDOT, estimating the economic costs of motor vehicle accidents (all vehicles, not exclusive to transit buses), the largest single cost component is property damage, which accounted for over a third of total economic costs. The high cost of property damage is primarily a function of the high incidence of minor crashes in which injury was either insignificant or nonexistent.[1] These figures may even be higher, but the FTA requires that only damage greater than $1,000 is reportable. Therefore, smaller, perhaps more frequent and costly incidents may be transparent at this level, but a fairly expensive indicator at a more in depth analytical level.

2.3 Economic Costs Associated with Motor Vehicle Crashes

Motor vehicle crashes affect both the individual crash victims, and society as a whole, in numerous ways. Economic costs associated with crash fatalities and injuries include:

- medical costs - cost of all medical treatment associated with motor vehicle injuries other than that given during ambulance transport
- emergency services - cost of ambulance or helicopter EMS transport and care, as well as police and fire department response costs
- vocational rehabilitation - cost of job or career retraining needed due to disability caused by motor vehicle injuries

---

1 Economic Cost of Motor Vehicle Crashes - 1994

- market productivity - present discount value of lost wages and fringe benefits over the victims remaining life span
- household productivity - present value of lost productive household activity, valued at the market price to hire someone else to accomplish remaining life span
- insurance administration - administrative costs associated with processing insurance claims resulting from motor vehicle accidents
- workplace cost - cost of workplace disruption due to the loss or absence of an employee (Includes the costs of retraining new employees, overtime needed to accomplish work of injured employee, and administrative costs of processing personnel changes.).
- legal/court cost - legal fees and court costs associated with civil litigation resulting from traffic crashes
- premature funeral cost - present discount value of paying for a funeral in the present instead of at the end of the victim's normal expected lifespan
- travel delay - value of travel time delay for persons who are not involved in traffic crashes, but who are delayed in traffic congestion caused by these crashes
- property damage - value of vehicles, and roadways, cargo, and roadways damaged in traffic crashes [2]

The cost of an automobile crash-related injury, at a maximum injury level of three, which is a midlevel severity, is $472.3K[3]* (estimated by the USDOT). And, the estimated value of a human life is $2.7M (These estimates are generally accepted by authors and researchers within the transportation industry, and are considered standard benchmarks for measuring the cost of a life and an injury.). The estimated cost of property damage related to a motor vehicle crash is $1.7K[4]. These estimates are in 1994 dollars, if factored out to 1999 dollars (using the GDP deflator), values would be increased accordingly.

Crash Related Injury = 515.1K
Human Life = 2.9M
Property Damage = 1814K

Therefore, the loss of human life or substantial numbers of severe injuries and property damage have an increasingly costly impact on society. If using the most recent SAMIS reporting year (1997), the figures are:

Crash Related Injuries	=	20,034	=	$103.2M per annum
Crash Related Deaths	=	101	=	$292.9M per annum

In total, bus related collisions cost society $395 million in 1997.

*This number includes the economic cost components outlined above and a valuation for reduced quality of life, as well as a "willingness to pay" factor.

2 Et. al.
3 Ibid.
4 Ibid.

2.4 General Estimates System Data Analysis

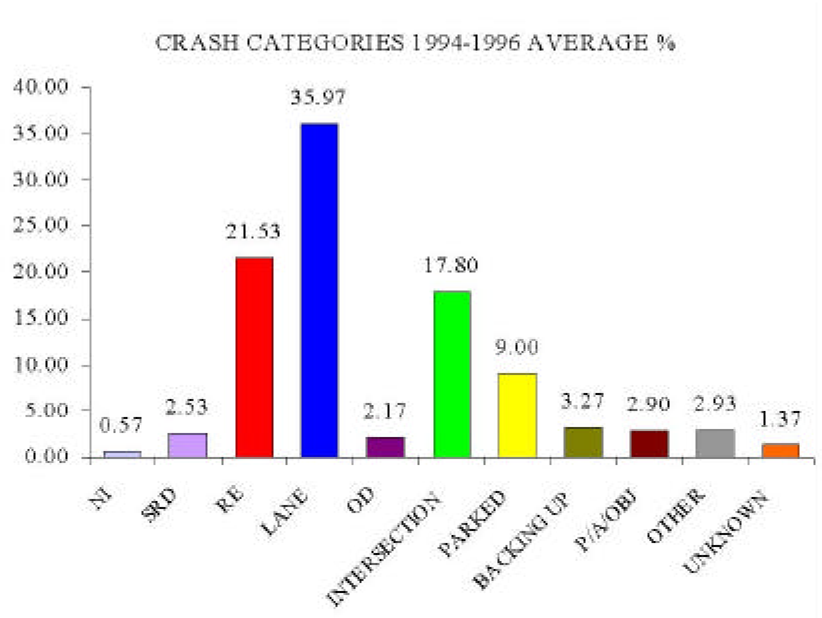
The National Automotive Sampling System (NASS) General Estimates Systems (GES) provides data about all types of crashes involving all vehicle types. The GES is used to identify safety problem areas, provide a basis for regulatory and consumer information initiatives, and form the basis for cost and benefit analyses of safety initiatives.

The GES obtains its data from a nationally representative probability sample selected from the estimated 6.8 million police-reported crashes which occur annually. These crashes include those resulting in a fatality or injury, and those involving major property damage. Although various sources suggest that many more crashes go unreported, one can assume that the majority of these involve only minor property damage and no significant personal injury. By restricting attention to police-reported crashes, the GES concentrates on those crashes of greatest concern to the safety community and the general public.

The police accident reports (PARS) from which GES data is derived is a probability sample of police-reported crashes that occurred in the United States. Since each crash occurring in the survey year has an equal chance of being selected, the design makes it possible to compute not only national estimates but also probability errors associated with the estimates. The national estimates produced from GES data may differ from the true values, because they are based on a probability sample of crashes and not a census of all crashes. The standard error of an estimate is a measure of the precision or reliability with which an estimate from the particular GES sample approximates the results of a census. For the purposes of this exercise the standard error rate of the data was approximately 1%. This data includes all vehicle types currently on the road in the United States. Thus, the data was extracted to apply only to motor coaches that had been involved in an incident between 1994 and 1996.

For the purposes of selecting baseline statistics, the data has been imported into statistical analysis (SPSS) and spreadsheet (EXCEL) packages. Simple cross tabulations, frequency trending and percentage functions have been applied. Predictors selected were: year, crash configuration (scenario), injuries, severity, corrective action, movement of vehicle prior to incident, critical event, striking vs. struck. Based on these data points, analysis was conducted to conclude frequency, probability, and ultimately, applicability to the Transit IVI program.
Data was first presented at the IVI Steering Group meeting held in Salt Lake City on February 26 & 27, 1998. The most salient discussion focused on the total crashes of motor coaches in the United States, and where the cluster points were. This was a significant milestone, as it was the first time that this type of quantitative national detailed data was examined. Previously, the Steering Group had discussed crash data based on individual transit systems and anecdotal data.

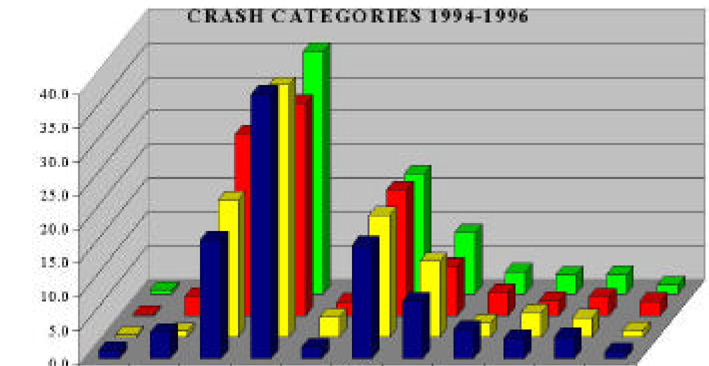
Figure 3 – CRASH CATEGORIES 1994-1996 AVERAGE



NI=Non-incident
SRD=Single Road Departure
RE=Rear End
Lane=Lane Change/Merge
OD=Opposite Direction
Intersection=Intersection
Parked=Parked Object
Backing Up=Backing Up
P/A/OBJ=Pedestrian/Animal/Object

As illustrated in the above graph, the five most frequent crash types involving a motor coach are: lane change, rear end, intersection, parked and backing up.

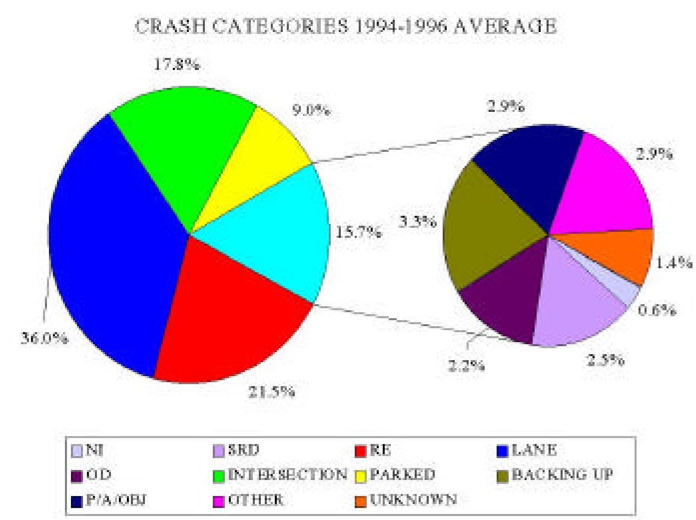
Figure 4 / Figure 5: CRASH CATEGORIES 1994-1996



	NI	SRD	RE	LANE	OD	INTERSECTION	PARKED	BACKING UP	P/A/OBJ	OTHER	UNKNOWN
1994	1.2	3.9	17.5	39.1	1.6	16.8	8.5	4.3	2.9	3.2	1.0
1995	0.3	0.8	20.2	37.3	2.9	18.8	11.2	2.1	3.6	2.8	1.0
1996	0.2	2.9	26.9	31.5	2.0	18.6	7.3	3.4	2.2	2.8	2.1
Average	1.57	2.53	21.53	35.97	2.17	17.80	9.00	3.27	2.90	2.93	1.37

NI=Non-incident SRD=Single Road Departure RE=Rear End Lane=Lane Change/Merge
OD=Opposite Direction Intersection=Intersection Parked=Parked Object Backing Up=Backing Up
P/A/OBJ=Pedestrian/Animal/Object

Further analysis of the data over a three year period, illustrates that there is an increase in rear end, intersection and parked incidents; and a small decrease in backing up and lane change incidents over the past three years. This will be discussed in detail.



NI=Non-incident SRD=Single Road Departure RE=Rear End Lane=Lane Change/Merge
OD=Opposite Direction Intersection=Intersection Parked=Parked Object Backing Up=Backing Up
P/A/OBJ=Pedestrian/Animal/Object

Further examination of the aggregate numbers of accidents reveals that the majority of crashes, 84% occur within the top four crash categories: lane change, rear end, intersection, and parked. The next most frequently occurring scenario is that of backing up, which has a frequency of 3%. Thus the total for the top five crash categories comprises approximately 87% of crashes involving motor coaches within the United States, between 1994 and 1996, according to the GES data system. The remaining 13% are comprised of: opposite direction, pedestrian, animal, object, single road departures, unknown. other, and non-incident.

Analysis of aggregate numbers indicated clear trends and implications: the five most frequently occurring crash types involving a motor coach are lane change, rear end, intersection, parked and backing up; there has been a small increase in rear end, intersection and parked incidents; and a small decrease in backing up lane change incidents over the past three years; the majority of crashes, 84%, occur within the top four crash categories: lane change, rear end, intersection, and parked; the next most frequently occurring scenario is that of backing up, which has a frequency of 3%; the total for the top five crash categories comprises approximately 87% of crashes involving motor coaches within the United States; the remaining 13% are comprised of: opposite direction; pedestrian, animal, object; single road departures; unknown; other; and non-incident.

Crash categories were selected, for more in-depth analysis, by the IVI Steering Group and the Acting FTA IVI Program Manager during a process involving user surveys during steering group meetings, and interviews with FTA and transit agency staffs. These crash categories were selected to either validate or invalidate the user services identified over the past year by the IVI Steering Group members. The user services identified are as follows:

- Lane Change and Merge Collision
- Forward Collision Avoidance
- Rear Impact Collision Mitigation
- Tight Maneuvering/Precise Docking

The crash categories selected are:

Backing Up
Lane Change
Rear End
Intersection
Parked

The following is a breakdown of each crash category with a brief description. Appearing after that is a narrative of the highlights of the in-depth analysis for the crash category, and finally a summary conclusion of implications relating to particular user service areas.

Accident Analysis

Accident Type: Backing Up

Description: The vehicle (bus) is backing up, from either a non parking position or parking position, and either strikes or is struck by another involved vehicle.

Narrative: In 1996, there were a total of 660 accidents that occurred while a bus was backing up. Of these 660 accidents, 295 incidents involved a bus backing up from a non-parked position and striking another vehicle by traveling over the right edge of the roadway. The remainder of these 660 accidents (365 incidents) occurred in which the bus struck a vehicle by entering another vehicles lane (traveling in the opposite direction).

In 1995, all incidents of this accident type resulted in the bus being struck by another vehicle. There were a total of 567 accidents, in which there were two critical events that lead to backing up incidents. Of the 567 accidents that occurred in this year, the majority, 295 occurred while the bus was stopped/or in the proper lane. And 263 occurred when another vehicle encroached from a driveway or alley access striking the bus. A small percentage of the total of this type of backing up accident was the result of a bus being struck while a vehicle encroached from some other access point. These nine incidents resulted in a total of one injury.

In 1994, there were a total of 668 accidents involving a bus that was backing up. Of these, 262 occurred when the bus struck another vehicle by traveling over the edge of the roadway, and 44 by violating another vehicle’s lane, traveling in the opposite direction. The balance, which is almost half of all of this type of accident for the year occurred during an encroachment, in which the bus struck another vehicle 362 times by encroaching from an alley or driveway. There were no injuries associated with this type of accident during the subject year.

In reviewing the data for all three years, it is interesting to note that consistently throughout the data, there was no corrective action taken to mitigate the impending accident.

Trends: The trend in the total number of backing up type accidents appears to be decreasing. But further inspections of trends in this accident type category illustrates, that while overall the trend is decreasing, the number of incidents in which buses are striking other vehicles is actually leveling off, rather than decreasing.

Figure 6: 1994, 5, 6 BACKING UP TOTALS

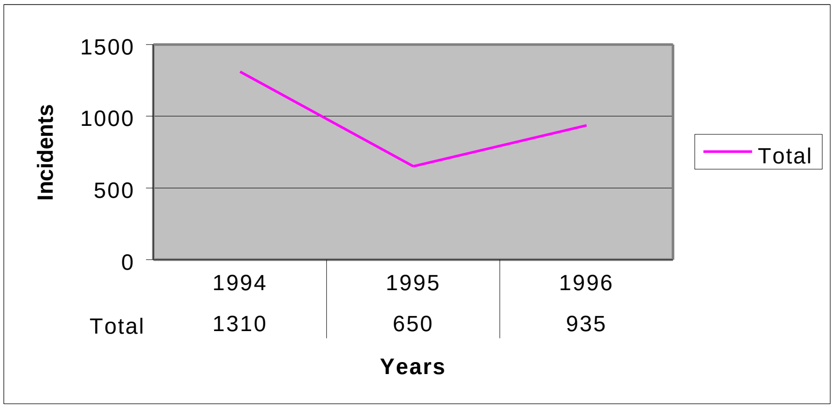
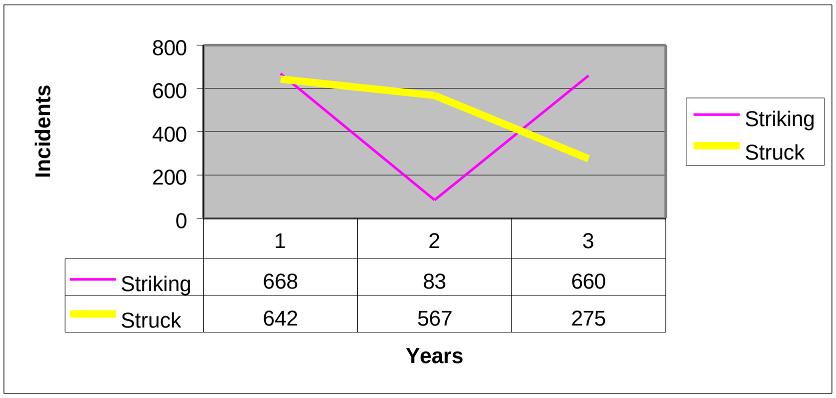


Figure 7: 1994, 5, 6 BACKING UP BY STRUCK & STRIKING



Note - - Numbers may not exactly match that cited in narrative due to rounding and/or exclusion of incidents coded in raw data as “unknown”.

Accident Type: Lane Change

Description: The vehicle (bus) is traveling forward, from a non-parking position, and either strikes or is struck by another involved vehicle. This type of accident occurs in the same trafficway, same direction and is a sideswipe angle or a change in trafficway vehicle turning (either same direction or turning into opposite direction).

Narrative: In 1996, the majority of accidents occurred in a scenario in which the bus was traveling straight and was struck by another vehicle, or struck another vehicle, in a side swipe motion. Cases in which the bus did the striking occurred approximately 2,841 times. Of these cases, there appears that there was no corrective action taken prior to the accident occurring. In terms of injuries, the greatest frequency occurred in the scenario in which the bus was traveling straight, and another vehicle was entering from a yield and encroached upon the bus. In this type of accident, there were 92 occurrences in which the bus was struck in which at least 12 injuries were reported. This accounts for approximately 2% of all sideswipe accidents that occurred in 1996. The other major type of accident categorized at lane change involves the vehicles turning (change in traffic vehicle turning). This type of accident accounts for about a third of all of this type. The majority of vehicle turning scenarios involved the bus striking another vehicle. Four out of five times the bus did the striking, and there was no corrective action taken by either vehicle. Injuries were negligible in this category, with 20 accidents in which two injuries were reported.

In 1995, the percentage of sideswipe accidents is different than that of 1996. The total number of sideswipe accidents was higher, 8,359 in 1995, as opposed to 5,101 in 1996. The split between striking and struck was much greater also. Of all of this type of accident, the majority occurred in which the bus was struck in about 60% of the cases. This is a 10% rise over 1996. Again, injuries were negligible, occurring in less than one percent of all cases. In terms of vehicle turning types of accidents, the frequency was much less with a total for the year of 3,400 accidents. There is an approximate 50/50 split as to striking and struck. The bus was struck 1,804 times, and struck another vehicle 1,591 times. Within this type of accident, the occurrence of corrective action is low, with only 12 reported instances of corrective action prior to the event. In all cases, injuries were negligible. Clearly, 2 out of 3 accidents occurred in a side swipe situation in which the slim majority of times the bus was struck.

Once again, in 1994, the occurrence of injury was negligible, occurring mostly in accidents in which the bus is traveling in a lane and struck by another vehicle encroaching. There were 263 occurrences in which one person was injured. In terms of comparison to overall, this is 23% of all vehicle-turning accidents in which the bus was struck, and only six percent of all of this type of vehicle turning accident. In terms of sideswipe scenarios, two out of three times, the bus was struck by another vehicle. Approximately ten percent of all accidents of this type were the result of another vehicle encroaching upon the bus.

Trends: Overall occurrences of lane change type accidents have decreased over the three-year period. They appear to have leveled off between 1995 and 1996. The breakdown between striking and struck illustrates that the occurrence of buses striking other vehicles is steadily rising in this lane change category. Conversely, the total incidents of buses being struck by other vehicles have decreased.

Figure 8: 1994, 5, 6 LANE CHANGE TOTALS

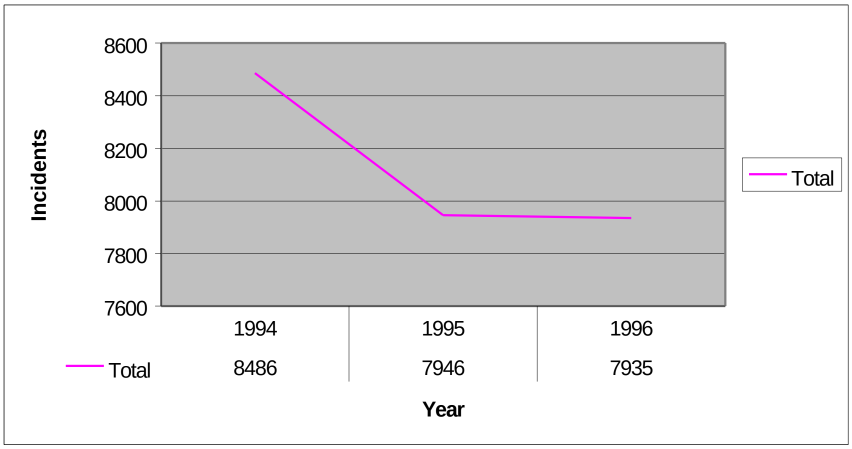
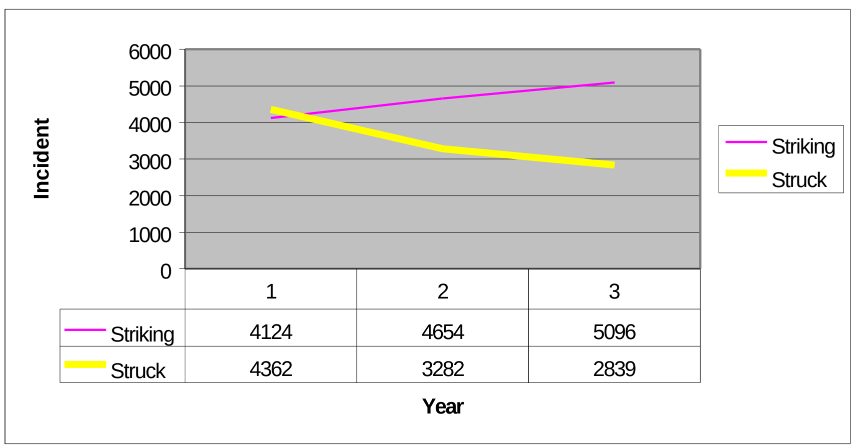


Figure 9: 1994, 5, 6 LANE CHANGE BY STRUCK AND STRIKING



Note - - Numbers may not exactly match that cited in narrative due to rounding and/or exclusion of incidents coded in raw data as “unknown”.

Accident Type: Rear End

Description: The vehicle (bus) is traveling forward, initially stopped, or decelerating, and either strikes or is struck by another involved vehicle. This is a same trafficway, same direction configuration.

Narrative: In 1996, there were approximately 7,510 rear end accidents in which the bus was moving forward and struck from behind. Of these, there were a number of scenarios in which another vehicle was involved. Those in which the bus struck one or more vehicles while traveling straight accounted for 1,082 incidents (approximately 14%). Of these, there were 401 accidents that resulted in one reported injury. Those in which there were more than two vehicles struck accounted for 476 accidents in which one person was injured. Approximately one third of this type involved more than two vehicles.

Of the 3,751 rear end accidents that occurred while the bus was initially stopped and was struck, all were the result of being struck by a tailing vehicle traveling at a higher rate of speed. The commonality in this is the critical event initiated by the other driver. In this scenario, the motor vehicle already in the bus' lane is traveling in the same direction with higher speed. The majority of these, 2,368, occurred while the bus was stopped and accounted for up to six injuries occurring in 3,360 accidents (approximately 90%).

Of those in which the bus was traveling in the same direction with higher speed, 307 accidents occurred, 24 of which produced one injury. And, in the case of the bus being struck by another vehicle, there were 549 accidents, of which the striking vehicle was either encroaching or trailing. These types of accidents accounted for up to two injuries in 59 cases, which are approximately 10%.

In those in which the bus was traveling forward and decelerating, all the accidents involved the bus striking at least one vehicle traveling in the same direction. There were 1,523 of this type with no injuries. Almost half occurred while traveling straight. The other approximate half occurred either while turning right or passing/overtaking another vehicle.

In 1995, there were a total of 4,940 accidents. The majority involved the bus being struck by another vehicle. Approximately, 75% or 3,643 accidents occurred in which the bus was struck; all of which reported no corrective action taken prior to the event. Of these, 497 accidents (or 10%) reported at least one injury. Almost 25% of this type of accident occurred while the bus was stopped in lane. Another 25% occurred while the bus was traveling straight but slowing down. Thus almost half of all this type of injury that occurred in 1995, involved a bus being struck from behind, either while slowing down or at a stop.

In 1994, there were a total of 5,063 rear end accidents, of these, once again the majority, 61% involved the bus being struck by another vehicle. And, all occurred while stopped in lane or decelerating. In all but 16 cases, no corrective action was taken prior to the event. Injuries were reported in approximately 23% of all accidents. But of these, 22% occurred when the bus was struck and only 1% occurred in which the bus did the striking.

Trends: For the three year period there appears to be a sudden rise in rear end type accidents. Further trending illustrates that the steady rise in this type of accident applies to both buses being struck by other vehicles and by buses striking other vehicles. But again, by far the majority of accidents occur in the being struck classification.

Figure 10: 1994, 5, 6 REAR END TOTALS

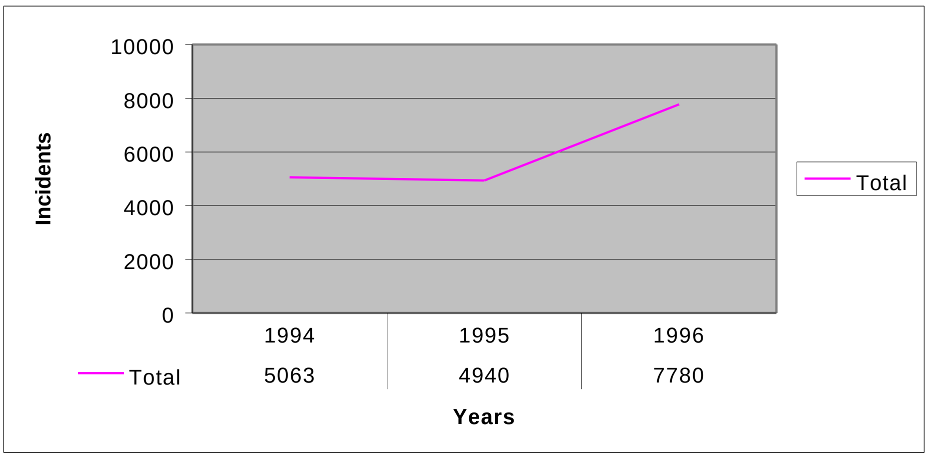
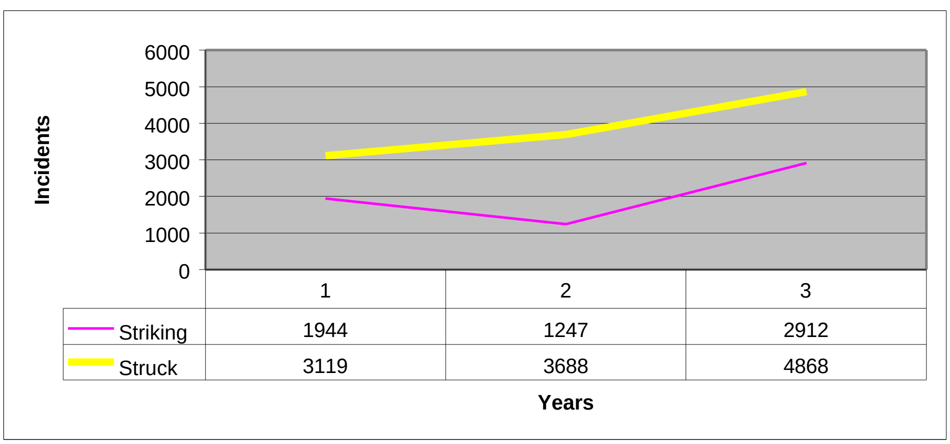


Figure 11: 1994, 5, 6 REAR END BY STRUCK AND STRIKING



Note - - Numbers may not exactly match that cited in narrative due to rounding and/or exclusion of incidents coded in raw data as "unknown".

Accident Type: Intersection

Description: The vehicle (bus) is traveling forward. It involves a change trafficway, vehicle turning or intersecting path scenarios. This is a same trafficway, same direction; opposite direction; intersecting and perpendicular directions configurations.

Narrative: In 1996, there were approximately 4,964 accidents involving buses at intersections. Of these, in 1,812 (or 36%) the bus struck another vehicle. Therefore, in 44% of all intersection accidents, the bus was struck by another vehicle. The majority of accidents occurred where a vehicle was turning. Intersection related accidents involving at least one vehicle turning account for approximately 3,205 accidents, or 65% of all intersection accidents involved at least one turning vehicle. Of these, 39% of the time the bus did the striking, and 61% of the time the bus was struck. Resulting injuries in this accident type are fairly low. Of all accidents, only 439 involved any reported injuries. Reported injuries resulting from vehicle turning accidents at intersections account for 13% of all accidents, with the majority (338 of 439 accidents or 77%) involving the bus being struck by another vehicle. In both striking and struck scenarios, the critical event that made the crash imminent appears to be encroachment at a junction. In 98% of the reported accidents of this type, encroachment was cited as the cause.

In 1995, there were approximately 3,318 accidents at intersections. Of these, 16% involved the bus striking another vehicle. In the majority of this type of accident, the bus was struck by another vehicle and encroachment is the cause in every case. Vehicle turning accidents accounted for 40% of all intersection related accidents in 1996. And injuries resulting from vehicle turning, intersection accidents accounted for almost half of all vehicle-turning accidents (212 reported at least one injury which is approximately 48%). The other half, or 60%, of all intersection related accidents occurred while on a straight path collision with another vehicle. This can be broken down further into striking and struck. In the vast majority of straight path, intersection type accidents in 1996, the bus was struck by another vehicle. This accounted for 87% of all straight path accidents. Of these, 494 resulted in at least one reported injury, or 25% (494 of 1,989 total straight path intersection accidents) of all of this type. And in all reported injuries, the bus was struck by another vehicle and encroachment was the leading cause by 68% (1,349 of 1,989).

In 1994, there were a total of 3,081 accidents involving a bus at an intersection. In 70% of all of this accident type, the bus was struck by another vehicle. Encroachment was the cause of all accidents. Once again, there were two scenarios, the first is a vehicle turning and the second is a straight path. There were 1,385 accidents that involved a vehicle turning. Of these, 838 involved the bus being struck by another vehicle (61%). All injuries occurred in cases where the bus was struck by another vehicle. This accounted for 192 accidents in which at least one injury was reported. Vehicle turning accidents in which there was at least one reported injury account for 14%.

The other 30% of all intersection related accidents for 1994 involve a straight path scenario. Straight path accidents in which the bus was struck account for the majority of this type of accident, 77% (1,236 of 1,613 of all straight paths). And of these, 66% (1,063) resulted in injury. The majority of injuries producing accidents are within the scenario of the bus being struck by another vehicle. These types of accidents account for a total 1,063 or 66%.

In all three years, there were only 346 reports of corrective action taken. This is only 6% of the total for all three years and clusters around straight path, intersection accidents, in which the bus was struck by another vehicle.

<u>Trends</u>: As illustrated, the incidents of buses striking other vehicles appears to be increasing, while the incidents of buses striking other vehicles appears to be steadily rising over the sample three year period. In total, the overall incidents of intersection related accidents in declining.

Figure 12: 1994, 5, 6 INTERSECTION TRENDS TOTALS

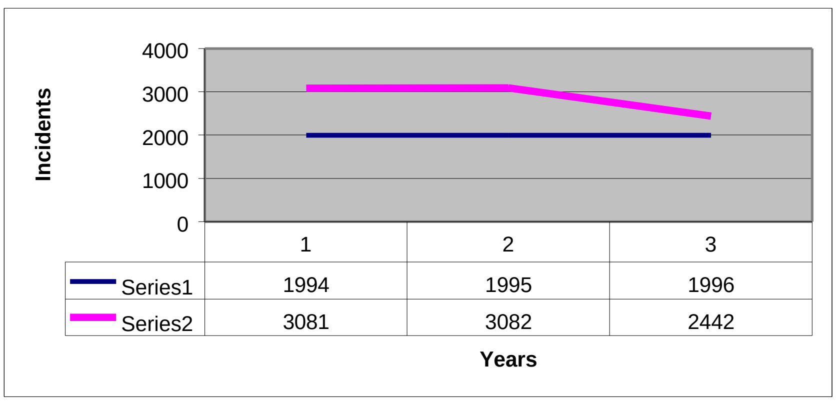
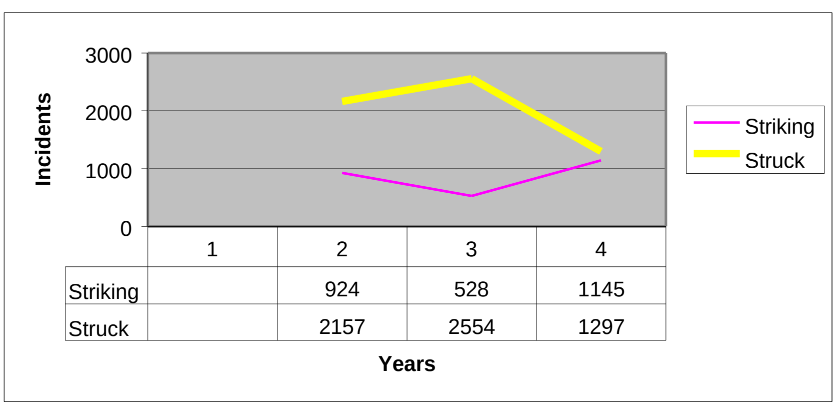


Figure 13: 1994, 5, 6 INTERSECTION TRENDS BY STRUCK AND STRIKING



Accident Type: Parked

Description: The vehicle (bus) is traveling in a designated lane, and strikes a parked vehicle on either side of the trafficway.

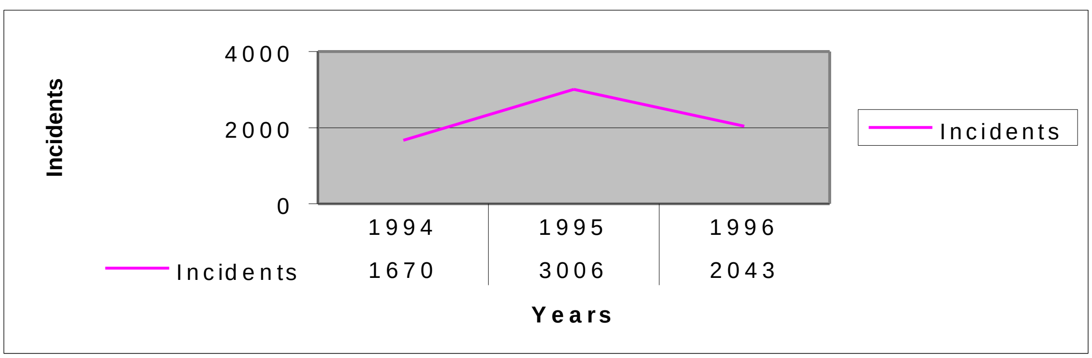
Narrative: In 1996, there were a total of 2,043 accidents in which a parked vehicle was struck by a bus. There were three scenarios. By far, the most common (1,446 accidents or 71%) occurred when the bus reportedly departed the right edge of the road while traveling straight. The other 30% are almost evenly divided between occurring while turning right (307) or while passing/overtaking another vehicle (290). These account for 15% and 14% respectively.

In 1995, there were a total of 3,006 parked vehicle type accidents. The majority of which were caused by road departure of the right edge. These accounted for 92% of these accidents. Another 8% or 244 accidents occurred because another vehicle initiated a critical event that caused the bus to strike the parked vehicle.

In 1994, there were 2,496 parked vehicle type accidents. Of these, 22% were attributed to loss of control. The other 78% were road departure, mostly over the right edge. Although there were 270 accidents in which road departure occurred over the left edge.
In all three years, there were no reported injuries as a result of this type of accident.

Trends: Accidents in which parked objects are struck by a bus rose from 1994 to 1996, but appear to have peaked in 1995.

Figure 14: 1994, 5, 6 PARKED BY TOTALS



Note - - Numbers may not exactly match that cited in narrative due to rounding and/or exclusion of incidents coded in raw data as “unknown”.

2.5 Probability vs. Severity

Using the risk assessment model outlined in Military Standard MIL-STD-882, which is the safety industry standard and the FTA recommended safety assessment procedure, crash scenarios were characterized as to hazard severity categories and hazard probability levels. The priority for system safety is to eliminate hazards in the early design phases. As the bus system is an already designed and operating system, this is not feasible. When hazards cannot be eliminated at design, a risk assessment procedure, based upon the hazard probability, hazard severity, as well as risk impact, is used to establish priorities for corrective action and resolution of identified hazards.

Hazard severity categories are defined to provide a qualitative measure of the worst creditable mishap resulting from personnel error, environmental conditions; design inadequacies; procedural deficiencies; or system, subsystem or component failure or malfunction.

Severity Categories

Category	Severity	Characteristics
I	Catastrophic	Death or System Loss
II	Critical	Severe Injury, Severe Occupational Illness or Major System Damage
III	Marginal	Minor Injury, Minor Occupational Illness or Minor System Damage
IV	Negligible	Less than Minor Injury, Occupational Illness or System Damage

The probability that a hazard will be created during the planned life expectancy of the system can be described in potential occurrences per unit of time, events, population, items, or activity. Assigning a qualitative hazard probability to a potential design or procedural hazard is generally not possible early in the design process. A qualitative hazard probability may be derived from research, analysis, and evaluation of historical safety data.

Frequency (Probability) Categories

Description	Level	Characteristic
Frequent	A	Continuously Experienced
Probable	B	Will Occur Frequently
Occasional	C	Will Occur Several Times
Remote	D	Unlikely but Can Reasonably be Expected to Occur
Improbable	E	Unlikely to Occur, but Possible

In reviewing the output of the GES data, limited to the top five crash scenarios, the following severity and probability (or frequency) categories were assigned.

Striking

Crash Scenario	Frequency (*f*) Per Ann.	3 Year	Sample	Average Severity (*s*)
Backing Up	16	45	0	.56
Lane Change	19	58	6	.23
Rear End	11	34	2	.72
Intersection	10	31	1	.81
Parked	33	100	5	0

Struck

Crash Scenario	Frequency (*f*) Per Ann.	3 Year	Sample	Average Severity (*s*)
Backing Up	17	55	1	.56
Lane Change	14	43	11	.23
Rear End	22	66	7	.72
Intersection	23	67	4	.81
Parked	N/A	N/A	N/A	N/A

Per Ann = average frequency per year, within crash category
3 Year = average frequency over three year period, within crash category
Sample = average frequency over three year period, within total sample (total sample=top five crash categories)

$f = \frac{NE}{N}$

$s = \frac{Smaxv}{N}$

Tolerance levels or thresholds were assigned based upon frequency (quarterly) in data spectrum and other risk indexes. Risk impact is assessed to discriminate between hazards having the same hazard risk index. This impact consists of the effect and cost of an identified risk in terms of mission capabilities, and social, economic and political factors.

Severity Thresholds
(Tolerance Levels)

.00 - .25	Negligible	(IV)
.26 - .50	Marginal	(III)
.51 - .75	Critical	(II)
.76 - 1.0	Catastrophic	(I)

Frequency Thresholds
(Tolerance Levels)

00 - 19	Improbable	(E)
20 - 39	Remote	(D)
40 - 59	Occassional	©
60 - 79	Probable	(B)
80 - 100	Frequent	(A)

Risk Matrix and Index

Frequency Of Occurrence		Category I Catastrophic	II Critical	III Marginal	IV Negligible
(A)	Frequent	IA	IIA	IIIA	IVA
(B)	Probable	IB	IIB	IIIB	IVB
©	Occasional	IC	IIC	IIIC	IVC
(D)	Remote	ID	IID	IIID	IVD
(E)	Improbable	IE	IIE	IIIE	IVE

IA, IB, IC, IIA, IIB, IIIA	Unacceptable (with review)*
ID, IIC, IID, IIIB, IIIC	Unacceptable (with decision required)**
IE, IIE, IIID, IIIE, IVA, IVB	Acceptable (with review)*
IVC, IVD, IVE	Acceptable

*review indicates regularly scheduled reexamination and reassessment (cyclical)

**decision indicates that immediate action is required

With these parameters, the following risk assessments were assigned to the five top crash scenarios, broken down between striking and stuck.

Crash Scenario	Striking	Struck
Backing Up	IIC	IIC
Lane Change	IVC	IVC
Rear End	IID	IIB
Intersection	ID	IB
Parked	IVA	N/A

Backing Up

Vehicle Role: Striking

Description: Occurs occasionally, with a critical severity.

Risk: Unacceptable

Vehicle Role: Struck

Description: Occurs occasionally, with a critical severity.

Risk: Unacceptable

Lane Change

Vehicle Role: Striking

Description: Occurs occasionally, with a negligible severity.

Risk: Acceptable without further review.

Vehicle Role: Struck

Description: Occurs occasionally, with a negligible severity.

Risk: Acceptable without further review.

Rear End

Vehicle Role: Striking

Description: Remote occurrence, but critical severity.

Risk: Unacceptable with a decision critical.

Vehicle Role: Struck

Description: Probable occurrence, but critical severity.

Risk: Unacceptable with review.

Intersection

Vehicle Role: Striking

Description: Remote occurrence, but catastrophic severity.

Risk: Unacceptable with a decision necessary.

Vehicle Role: Struck

Description: Probable occurrence, but catastrophic severity.

Risk: Unacceptable with review.

Parked

Vehicle Role: Striking

Description: Frequent occurrence, but negligible severity.

Risk: Unacceptable with a decision critical.

Vehicle Role: Struck

Description: No data to support analysis.

Risk: None.

2.6 Conclusion of Hazard Assessment

In prioritizing the five major crash scenarios, based on a hazard risk assessment, the following array, in order of appearance, is evident:

Scenario	Color	*f*	*s*
Intersection (struck)	red	67	.81
Rear End (struck)	red	66	.72
Intersection (striking)	yellow	31	.81
Rear End (striking)	yellow	34	.72
Backing Up (struck)	yellow	55	.56
Backing Up (striking)	yellow	45	.56
Lane Change (striking)	green	58	.23
Lane Change (struck)	green	43	.23
Parked (struck)	green	100	.00
Parked (striking)	N/A	N/A	N/A

Therefore, using the hazard risk assessment and prioritizing the above crash scenarios, most emphasis should be placed upon Intersection type accidents in which the bus is struck by another vehicle, and Rear End type accidents, in which , once again the bus is struck by another vehicle. Both of these types of accidents experience a high frequency rate and result in the most severe outcomes. Next, in terms of prioritization, are the yellow, or mid level crash types. These include: Intersection and Rear End, in which the bus strikes another vehicle; and Backing Up, in both the striking and struck scenarios. These mid level type of accidents tend to occur less frequently with lower severity levels. At the lowest level of priority are the lane change types of accidents. Although they occur with approximately the same frequency as those assigned a yellow designation, they have a much lower severity. And, thus, they are assigned a lower priority. And last, are the parked scenarios. Parked scenarios were assigned the lowest priority, as there was a severity rating of zero.

2.7 Sample Transit System Data Analysis

As part of the baseline statistics study, attempts were made to assess data from a sample set of systems. The intent was to compare the GES data to that of "real" transit agency crash data. Unfortunately, most attempts at acquiring the data were unsuccessful. Below is a subset of rear end incident data from a sample agency. It is worthy to note that this small sample of data directly confirms that of the GES data, but still warrants further investigation. This may be a critical need factor in the future of the IVI transit project. Data collection of actual transit collisions to this level of involved vehicle action, could facilitate a more in depth study of causal analysis.

Description: The vehicle (bus) is traveling forward, initially stopped, or decelerating, and either strikes or is struck by another involved vehicle. This is a same trafficway, same direction configuration.

Narrative: When examining the data, it was noted that there was only one quarter of data reported for 1999, therefore a simple extrapolation was done to forecast the year. The assumption was that if this were the result of a typical quarter, the full year of data would be equal to four times this number. This appears to complete the data in a consistent manner and behavior.

Although, both types of accidents appear to be level, it is of note that also, the ratio of struck to striking remains constant at about 5:1. Thus, buses are being struck by other vehicles five times more often than doing the striking. This appears to confirm the results of the GES data analysis.

Trends: For the three-year period, there appears to be a leveling off in rear end type of accidents. But overall, there is a slight rise in this type of accident. In examining the strike vs. struck scenarios, it is interesting to note that the occurrence of buses being struck by other vehicles is leveling off, while the incidence of buses striking other vehicles in a rear end scenario, appears to increasing by less than 1%.

Figure 15: 1994, 5, 6 REAR END TOTALS – SAMPLE TRANSIT

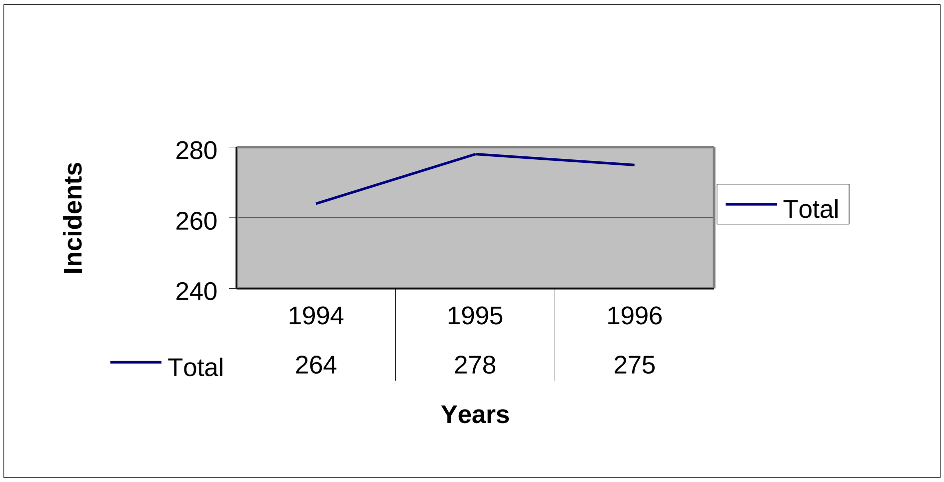
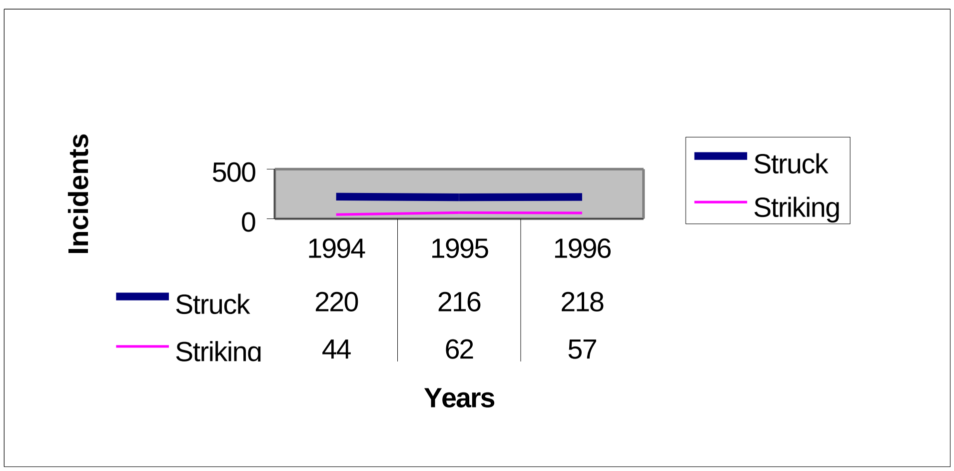


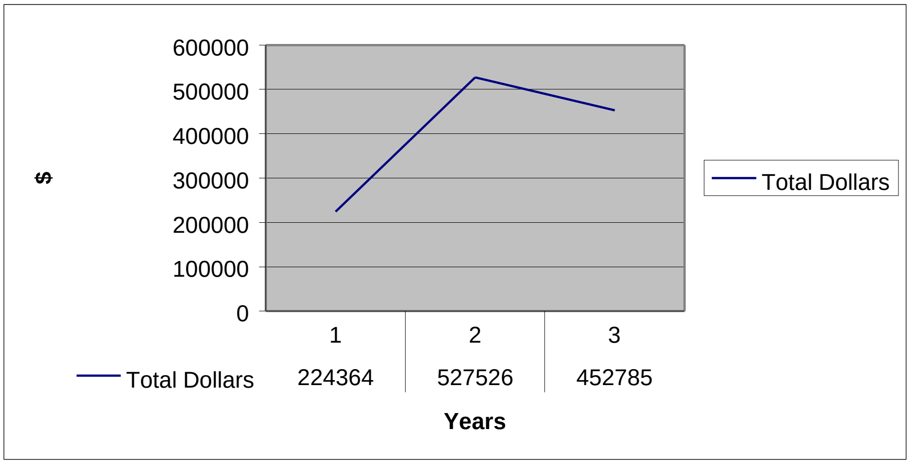
Figure 16: 1994, 5, 6 REAR END BY STRUCK & STRIKING- SAMPLE TRANSIT



2.7 Sample Transit System Property Data

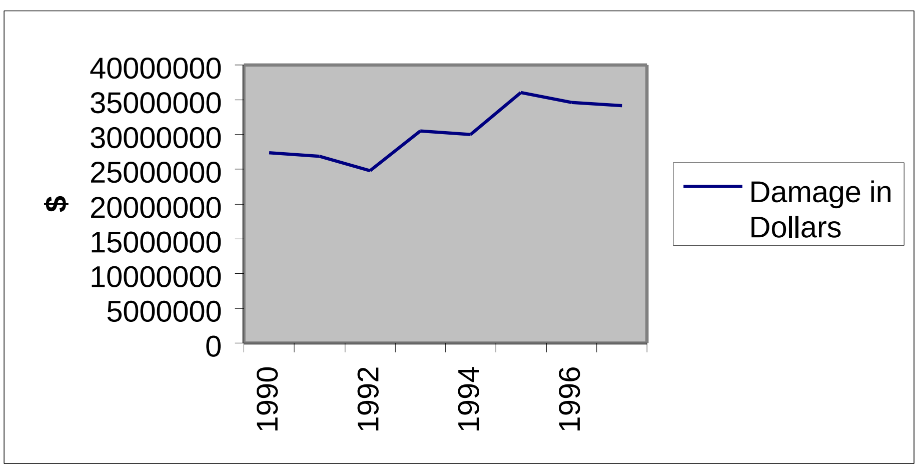
In reviewing the data from the sample transit system, it was interesting to note that property damage was indicative of a "leak" in the revenue stream. As illustrated, over the three-year period, there was a doubling in the property damage value.

Figure 17: SAMPLE SYSTEM PROPERTY DAMAGE TOTALS



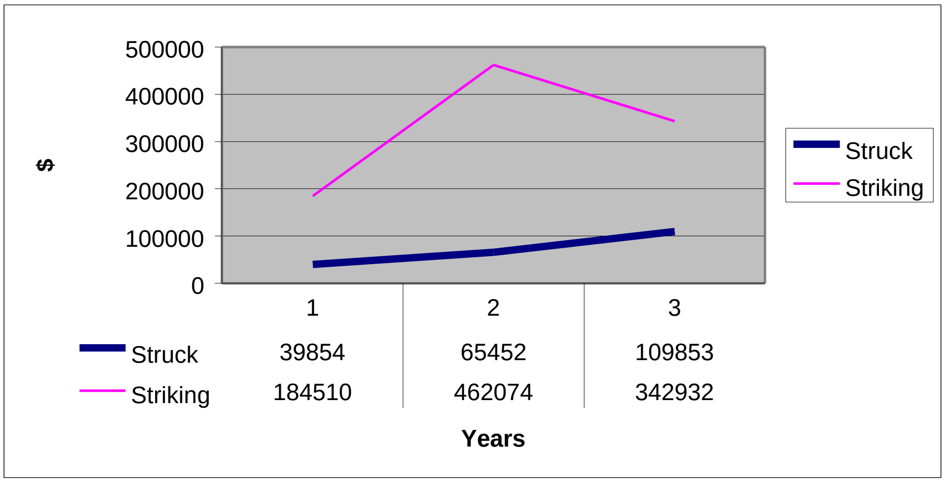
Compared to the national trend as reported earlier, there is quite a difference, which should be explored further with more sample transit systems' data. But it is evident that overall property damage data indicates a substantial loss.

Figure 18: PROPERTY DAMAGE - - BUS INCIDENTS



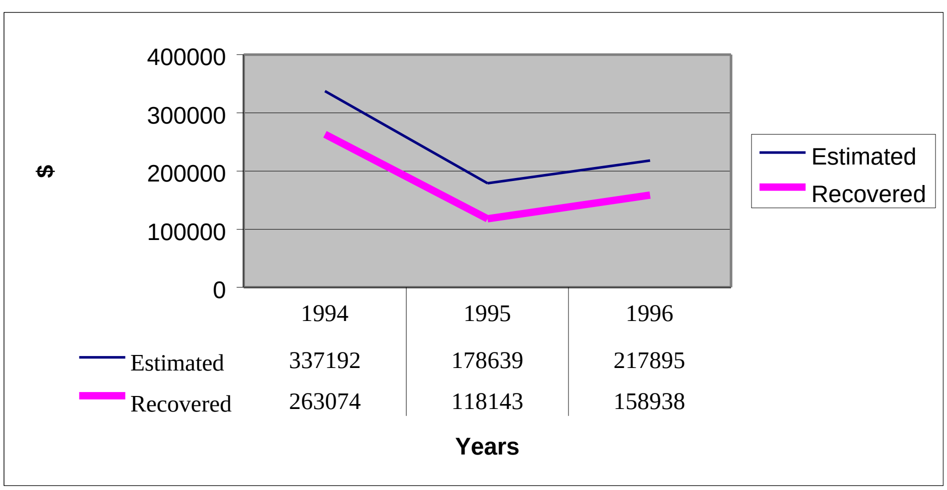
A closer look at the data, separating out the “striking” incidents from the “struck” incidents, reveals that the most expensive incidents are those in which the bus does the striking. This begs the question, is there a greater need for forward looking sensors?

Figure 19: SAMPLE SYSTEM PROPERTY DAMAGE



One final snapshot of property damage values illustrates the dichotomy between estimated and recovered losses. This differs from earlier figures, as it is the estimated, as opposed to the reported. As can be seen, there is an average delta of more than 30% unrecovered. As the bulk of these claims are in the “striking’ scenarios, there is a great loss occurring in this type of accident. And, it appears that this is rising. It would be beneficial to examine this type of “real life” data from other transit systems.

Figure 20: PROPERTY DAMAGE ESTIMATED VS. RECOVERED



2.8 Data Constraints and Advantages

As with any data source, there are some constraints and advantages with each set examined and are outlined below.

- GES allows for motorcoaches (double-axle vehicles), but may include intercity buses as well.
- GES has the correct level of detail for the type of analysis needed. i.e. causal data.
- GES is a statistical sampling, and as such, is not a compilation of actual totals.
- NTD is transit specific, but does not have the accident detail necessary for IVI purposes, i.e. causal data.
- FARS has the right detail, but it only addresses fatalities. Transit has relatively few fatalities, and data is difficult to parse by selected accident types.

There is a critical need for real life data gathering that is transit specific. One important scope item to the projects listed in **Current and Proposed Applications and Related Projects** section of this report is that each IVI project will collect transit-specific bus data for future use. It is strongly recommended that transit-specific causal accident data be gathered to further assess the current and ongoing needs of the Transit IVI Program.

Figure 21

SUMMARY MATRIX

Crash Scenario	Hazard Color	¦	s	Corrective Action	Trend Rise/Fall	% of Top 5	User Service
Intersection (struck)	red	67	.81	44%	↓	10%	LC/MC
Rear End (struck)	red	66	.72	0%	↑	19%	RICM
Intersection (striking)	yellow	31	.81	1%	↑	4%	LC/MC
Rear End (striking)	yellow	34	.72	59%	↑	10%	FCA
Backing Up (struck)	yellow	55	.56	0%	↓	2%	TM/PD
Backing Up (striking)	yellow	45	.56	0%	→	2%	TM/PD
Lane Change (striking)	green	58	.23	8%	↑	23%	LC/MC
Lane Change (struck)	green	43	.23	4%	↓	17%	LC/MC
Parked (struck)	green	100	.00	0%	↑	11%	FCA
Parked (striking)	N/A	N/A	N/A	N/A	N/A	N/A	N/A

LC/MC = Lane Change/Merge Collision Avoidance

RICM = Rear Impact Collision Mitigation

FCA = Frontal Collision Avoidance

TM/PD = Tight Maneuver/Precise Docking

2.9 Conclusions

In terms of crash scenarios with the greatest risk, producing the most severity, which are candidates for IVI applications, the primary candidate is intersection type crashes in which the bus is struck by another vehicle. Next in the list of priority is that of rear end type collisions in which the bus is struck by another vehicle. In addition to the risk and severity factors, these types of crashes account for almost one third of the top five scenarios. In particular, it appears that the rear end and struck type of crash is on the rise, as demonstrated by trending over the past three years. Thus, lane change and rear end collision mitigation technologies are appropriate.

Mid level types of accidents, which carry a medium range of risk and severity, include the other half of the intersection type, in which the bus strikes another vehicle; rear end, in which the bus does the striking and both backing up type crashes. These account for another 14% of all accidents within the top five. And, all except rear end in which the bus strikes another vehicle have a low corrective action rate. Therefore, collision mitigation and tight maneuvering technologies are applicable and appropriate.

Last, there is some contradictory emphasis in the data analysis. Although lane change type accidents account for almost half of the entire top five, they have a low severity, and therefore, are assigned a low priority. These types of accidents should not be discounted as they may impose a huge burden of cost and other resources upon transit operators, in terms of equipment and personnel down time, administrative burden, liability and other societal costs. It is difficult to calculate the cost of the average transit accident, as most are estimates of damage based upon reportable thresholds. According to the NHTSA, “motor vehicle crash costs funded through public revenues cost taxpayers $13.8 billion in 1994, the equivalent of $144 in added taxes for each household in the United States”.[5] Thus, reduction of the majority of bus related accidents could result in realized savings to the general public in property damage and economic costs to society, as well as revenue savings to the transit industry.

This study confirms the anecdotal information provided by the Transit IVI Steering Committee at both the Salt Lake City and Houston meetings. It is apparent that the user services selected for technology application could be of direct relevance in the mitigation and avoidance of certain crash scenarios involving transit buses. In particular, the data supports the application of technologies in the areas of lane change/merge collision avoidance and rear end collision mitigation.

Baseline statistics proposed as benchmarks in measuring the effectiveness of proposed operational tests in these areas should include, but not be limited to: frequency and severity of accidents, injuries and fatalities, vehicle role, corrective action, movement prior to critical event, critical event, and damage costs. An effective benchmark would be a reduction in critical factors:

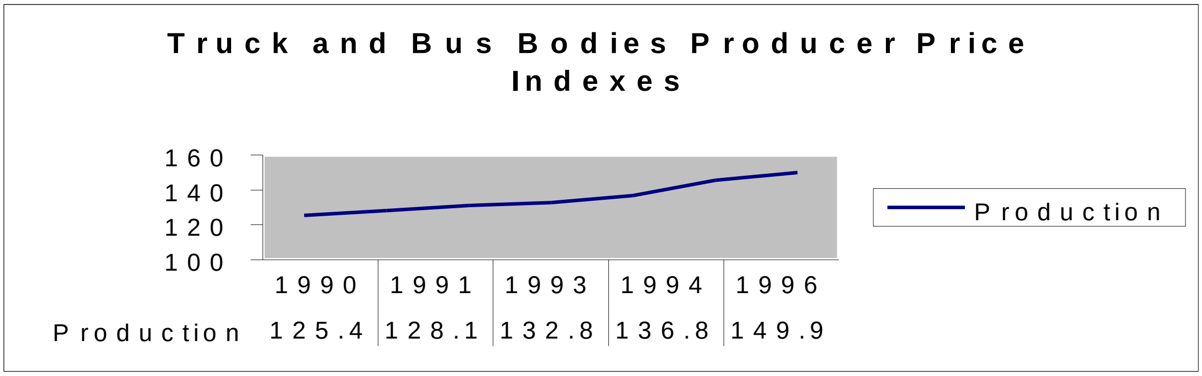
5 The Economic Cost of Motor Crashes, NHTSA.

overall incidents, injuries/fatalities, and costs. Further analysis of the data, such as location of damage, date and time, and geographical location, is suggested to assist in the placement of sensors in support of proposed operational tests.

CHAPTER 3: CURRENT AND FUTURE TRANSIT NEEDS

In order to complete the Needs Assessment for the Transit IVI program, it is necessary to examine current and future needs of the transit industry, and within that, define the future environment. In conjunction with FTA goals, it is an attempt to assess current transit needs related to safety and security, normal driving, and system operations. For these same areas, future transit needs have been assessed based on expected changes in passenger and driver demographics, transit service type and performance requirements, and the operating environment in terms of traffic and road conditions.

Manufacturing Indexes



Production of truck and bus bodies has increased steadily over the past 15 years, indicating a constant market for bus delivery.

3.1 Transit Industry Problems and Issues

As identified by executives within the transit industry, various environmental forces have hindered its vitality. Many of these factors stem from the way funding support for the industry has declined. In part, the decreasing funding base has left the industry less able to compete with other forms of transportation and therefore less attractive to potential customers. Below are a number of bullets elaborating.[6]

- Reduced government funding has left a historically subsidized transit industry with severely limited budgets.
- Heavy subsidization to the auto industry has enabled it to spend relatively more resources than transit toward attracting potential customers.
- In an effort to adjust to limited budgets, many transit systems find themselves cutting service and increasing fares regularly.

---

6 These points are extrapolated from: Research Results Digest; "Creating a New Future for Public Transportation: TCRP's Strategic Road Map"; Transit Cooperative Research Program (TCRP); April, 1998; Number 24.

- The transit industry, with increasingly limited funding, finds itself bearing the costs of expensive technologies and infrastructures necessary to support their systems. This often translates into serving customers less effectively.
- Due to urban sprawl, many people live and work in the suburban areas and have complex trip chains. This often means limited accessibility for these customers to transit service, thereby reducing its attractiveness.
- Transit industry officials also have pointed to negative perceptions of the industry as a deterrent to many customers.
- The transit industry also mentions problems within its capacities to serve, via demoralized workers or union interests, which may not wholly synchronize with those of the executives.

3.2 Federal Transit Administration Goals

The "FTA 5 Year Plan" identifies a number of transit goals within the next few years, as well as longer term goals. Several categories cover these goals, including passenger safety and security, equipment and infrastructure, and fleet operation programs. The IVI initiatives correlate to these goals in a number of different ways.

Safety and Security - The overall strategic goal of Safety and Security is to "achieve the highest practical level of passenger safety and security in all modes of transit through training, technical assistance, innovation, and technology."[7] Various goals and points support this overarching one. IVI technologies are one important way to achieve better safety and security on transit, by both reducing transit accidents and fatalities. Increased safety from the introduction of IVI will also lead to improvements in efficiency, with less operator and vehicle downtime, and better utilization of administrative time. Reducing incidents also reduces the corresponding cost of those accidents. The reduction in incidents will also encourage a greater feeling of security on the part of the riding public, and will help to promote increased ridership.

Transit Equipment and Infrastructure - The overall strategic goal is to "achieve the highest level of passenger service and comfort by applying technology to increase the capacity and quality of transit service."[8] Within this overarching strategic goal, the agency prioritizes several objectives, including the following:

- Increase and improve new bus and overall service reliability.
- Reducing travel time by 20% from current estimates.
- Reduce the economic cost of transportation.
- Deploy Advanced Technology Transit Bus (ATTB) program technology in 20 metropolitan areas.
- Deploy Communication Based Train Control (CBTC).

---

7 FTA Five Year Plan; Federal Transit Administration; 1998; P. IV-4.
8 FTA Five Year Plan; Federal Transit Administration; 1998; P. IV-6.

Fleet Operations - The strategic goal of fleet operations is "to shape America's future by ensuring a transportation system that is accessible, integrated, efficient, offers flexibility of choices, and can advance America's economic growth, and competitiveness domestically and internationally through efficient and flexible transportation." Some pieces to support this goal include:

- Support research of ITS ergonomics as well as refine individual ITS components, and operational tests on technologies such as Autonomous Dial-A-Ride Transit (ADART) and automatic fare collection systems.
- FTA will conduct workshops on rural ITS and assist the Transit Standards Consortium.
- Develop policy guidance on consistency with national architecture and standards that will help the transit community achieve ITS systems integration, interoperability, and compatibility with other transportation operators.

3.3 Demographic Trends and Their Impacts for Transportation and Transit

Discussed below are several of a number of demographic factors with clear trends that impact on transportation and transit. They include population growth, aging, disability, migration and shifts in employment, work and family, racial and ethnic diversity, welfare to work, and transit market share. The provision of transit that is safety conscious, mobility oriented and efficient will be in tune with these trends.

Population Growth Trends

As the population increases, the aggregate increase in the number of trips and miles can be expected to effect: transportation-related injury and fatality rates, environmental quality, and demand for transportation infrastructure.[9] Here is an area where safer vehicle technologies can stem the expected increase in transportation-related incident rates.

Aging Population Trends

Accessible transportation alternatives are necessary for maintaining older Americans' opportunities for independent living and their access to necessary goods and services. The growth in the older American population will also increase demand for elderly friendly fixed route vehicles, Americans with Disabilities Act (ADA) paratransit and other transit services. Technologies that enhance precise bus positioning will be very meaningful in this area.

Migration and Shifts in Employment Trends

Increased traffic congestion (Americans currently lose 1.6 millions hours a day due to traffic congestion). Transit's congestion management role will become more critical as highway congestion increases. The best use of public transit bus resources will be aided by the implementation of IVI technologies that allow buses to move in the most efficient manner possible.

---

9 The Impact of Trends on Transportation and Implications for FTA's Program; USDOT; <http://www.fta.dot.gov/library/intro/sp215.htm>.

These trends, and other related demographic shifts, are important to recognize in developing the next generation of transit buses.

3.4 Related Transit Technology Initiatives

Several examples point out relevant transit technology initiatives, including: an ITS APTS Program Support Outreach in Reston, Virginia, an Automated Passenger Information System in Metropolitan Dade County, Florida, Customer Information, Ridesharing, and Advanced Fare Systems Evaluations project through the Volpe National Transportation Systems Center in Cambridge, Massachusetts.

The ITS APTS Program Support Outreach in Reston, Virginia supports the FTA and will send program information to the transportation community and the general public. The project will also foster the transit industry's understanding, adaptability and deployment of advanced technologies for public transportation.[10]

Metropolitan Dade County has equipped its vehicle fleet with automatic vehicle location and monitoring equipment and can offer real-time passenger information to their customers using the existing infrastructure to support a multimodal transportation service. Metro-Dade Transit Agency uses this project as one means of providing customers with an automated trip planning capability, including real-time, online route and schedule information. Soon, information kiosks will be established at major rail and bus transfer points.[11]

The Customer Information, Ridesharing, and Advance Fare Systems Evaluations project will evaluate and study increased public transportation and ridesharing to help transit operators procure Smart Traveler and Smart Intermodal advanced technology systems. The project will provide its results to the transportation and transit communities, as well as the general public. The results will also help develop specifications for advanced electronic fare collection, interactive and real-time customer information systems, multimodal and multi-operator seamless fare systems, and real-time dynamic ridesharing systems.[12]

Over the next two years, the APTS Metropolitan Program will address spectrum analysis, rail analysis, transfer compatibility under the ADA, and traveler information. The next few years also show several research components for the APTS Rural Program, including Rural AVL, provider coordination, paratransit, rural fleet management and maintenance, and Rural Traveler information. All elements of APTS show a major focus on drawing technical support, outreach

---

10 APTS (Advanced Public Transportation Systems) Program Support-Outreach; MathCraft, Inc.; September 1995-November 1996.
11 Automated Passenger Information System-Miami; Metropolitan-Dade Transit Agency; July 1995-September 1997.
12 Customer Information, Ridesharing, and Advanced Fare Systems Evaluations; Volpe National Transportation Systems Center; May 1995- March 1996.

through workshops and architecture seminars, service plans, focus on regions, and a transition for integrated ITS over the next five years.[13]

BRT – Intelligent Transportation Systems Initiatives

Intelligent Transportation Systems (ITS) technologies are expected to be an integral part of the design and implementation of the Bus Rapid Transit (BRT) initiative. ITS technologies, when applied to BRT, can enhance the service of the system in terms of reliability, efficiency, and safety. The FTA is interested in seven ITS functional areas as they relate to BRT: ITS standards and architecture, automated fare collection, real-time passenger information, intelligent vehicle initiative technologies (which is the focus of this report and already thoroughly discussed), signal priority, advanced parking management, and enhanced passenger security. The following discussion summarizes each functional area and identifies possible roles within BRT systems.

ITS Standards and Architecture

According to TEA-21, all projects containing ITS must conform to the National ITS Architecture and Standards. The National ITS Architecture provides a framework for building an integrated, multi-modal, intelligent transportation system. The National ITS Architecture should be used as a tool to aid in the development of a BRT system that is compatible with other ITS systems in the region. The Department of Transportation in October of 1998 issued interim Guidance on conformance. A notice of proposed rule making regarding the final policy is expected in Fall 1999.

Automated Fare Collection

Automated fare collection applications to BRT will allow riders to quickly board BRT vehicles without having to struggle with bills, coins, tokens, or exact change. In addition, automated systems, may allow multi-door boarding, and will reduce backdoor management operations. Automated fare payment systems may also be integrated with parking services and other modes of transportation to provide a seamless transportation system for the passenger.

Real-Time Passenger Information

There are two separate users of real-time passenger information: riders en-route and passengers waiting to board a station or stop. Real-time passenger information provides en-route transit users with information such as schedule adherence, current incidents, weather conditions, and special events. Passengers waiting to board are provided with information on transit routes, schedules, transfer options, fares, real-time schedule adherence, current incidents, weather conditions, and special events. In addition to general service information, tailored information (e.g., itineraries) can also be provided to passengers.

---

13 FTA Five Year Plan; Federal Transit Administration; 1998; Section IV.

Signal Priority

Transit signal priority will utilize traffic signal prioritization technologies as an active transit schedule adherence tool. Transit priority can be used to extend green times, to allow buses behind schedule to get back on schedule.

Advanced Parking Management

Advanced parking management systems include the monitoring and management of a parking facility utilizing ITS technologies. Technologies include driver guidance to available parking facilities, notification of parking availability, parking reservations, space assignment and automated fee collection through an integrated fare payment system.

Enhanced Passenger Security

For the transit riding public, security is a critical issue. Passengers are more likely to utilize transit if their sense of security is high. Enhanced passenger security provides the capability to report an emergency and obtain assistance while the vehicle is in transit or the passenger is waiting to board. Silent alarms installed on the vehicle can be used to notify a central management center of an emergency situation. In addition, emergency call box buttons installed at sops can also be used to obtain assistance.

3.5 Transit Bus Safety and Operating Performance

Various levels of bus system safety have measures. Some are listed below.

- The number of transit fatalities, injuries and incidents per 100 million transit passenger miles. (1996)
- The number of transit crimes against patrons, transit employees and property. (1996)
- The number of transit properties in urbanized areas over 200,000 population with transit security plans. (1998)[14]

All of these measures have corresponding goals that aim to reduce these numbers, using the year in parentheses as a baseline. In addition, Bus Rapid Transit aims for research about case studies, followed by modeling Bus Rapid Transit for impacts on service, passengers, cost, and benefits.[15]

3.6 Potential Intelligent Vehicle Initiative (IVI) Applications For Transit

The various IVI goals identified by the FTA, and current demographic trends shape the future viability of transit. The potential applications of IVI can help define transit's future. Below are

14 <http://www.fta.dot.gov/library/intro/sp217a.htm>

15 FTA Five Year Plan; Federal Transit Administration; 1998; Section IV.

some potential IVI applications that may address some of the needs, issues, and problems have been identified.

The importance of providing the environment for IVI in transit is clear. "The near-term emphasis for the IVI will be defining specific IVI service characteristics that are beneficial to mass transit and ITS users at large. User service requirements and service integration will also occur and demonstration sites will be selected. Over the long-term, IVI will be deployed and mainstreamed."[16]

Various IVI applications enable enhanced safety and efficiency within transit. The USDOT RFI identifies many potential IVI applications within transit. Some of these applications can be broadened within the transit arena. Still others identified outside of transit may have transit relevant uses.

Some of the transit related IVI applications that potentially boost efficiency and safety include:

- An in-vehicle collision avoidance/warning system
- An in-vehicle obstacle and pedestrian warning system
- An in-vehicle passenger monitoring system
- A precision docking system
- A real-time transit passenger information network that gives transit passengers and driver real-time information about the transit network during their travel
- Fully automated vehicle control at a given facility, or in dedicated HOV lanes
- Intersection collision avoidance systems
- Railroad crossing collision avoidance systems
- Cargo/passenger identification
- Safety event recorders

If application is prioritized around densely populated elderly or disabled areas (such as elderly homes or hospitals) safety may increase in these areas. Several examples are below.

- The obstacle/pedestrian detection service would be an in-vehicle system that warns the driver when pedestrians, vehicles, or obstacle are near the driver's projected path.[17]

- Tight maneuvering/precision docking aids with both ADA and elderly riders in the loading and unloading of passengers.

---

16 FTA Five Year Plan; Federal Transit Administration; 1998; pp. 8-10.
17 *Intelligent Vehicle Initiative; Request for Information;* <http://www.its.dot.gov/ivi/rfi205.htm> or Federal Register: December 23, 1997 (Volume 62, Number 246), pp. 67107-67113.

- Vision enhancement is a service that would use infrared radiation from pedestrians and other objects to provide the driver with an enhanced view of the road ahead.

- Collision avoidance/warning systems that would assist the driver in detecting impending crashes in cluttered urban settings.

CHAPTER 4: APPLICABLE TRANSIT IVI SERVICES

IVI Services, such as those described in the RFI, have been identified, described, and related to transit needs. Attempts have been made to determine the availability of the service-related technologies, and their potential in overcoming the various transit needs.

Originally (May 1998), there were nineteen prime potential candidate user services identified:

Rear End Collision Avoidance*****
Road Departure
Lane Change & Merge Collision Avoidance*
Intersection Collision Avoidance
Grade Crossing Collision Avoidance
Vision Enhancement
Location-Specific Alert & Warning
Automatic Collision Notification
Low Friction Warning
Driver Comfort & Convenience
Vehicle Stability Warning & Assistance
Driver Condition Warning
Vehicle Diagnostics*
Platooning
Automated Maintenance*
Safety Event Recorder
Tight Maneuvering/ Precise Docking*
Passenger Monitoring
Rear Impact Collision Mitigation*

At the time, starred items were considered to be prime candidates for a transit application

Based on industry surveys and transit data analysis, four user services have been identified for transit, high priority IVI user services. These services focus most particularly on the safety of the driver and the vehicle in preventing accidents. Using systems that enable drivers to process information, make better decisions and operate vehicles more safely are the strong points of the following four priorities:

Lane Change and Merge Collision Avoidance

This feature will provide various levels of support for detecting and warning the driver of vehicles and for vehicles and objects in adjacent lanes (e.g. “blind spot” warning for early implementation). Later systems would introduce capabilities that will provide merge advice and/or warnings of vehicles in adjacent lanes, whose position and relative velocity make the planned lane change unsafe. Those capabilities would potentially include speed and steering control intervention for enhanced collision avoidance. This transit work will build on previous work performed by the NHTSA. However, the new focus will be on transit vehicle characteristics, the operating environment, driver capabilities, and driver inattention.

Forward Collision Avoidance

This feature will sense the presence and speed of vehicles and objects in the vehicle's lane of travel and will provide warnings and limited control of the vehicle speed (coasting or downshifting) to minimize risk of collisions with vehicles and objects in front of the equipped vehicle.

Rear Impact Collision Mitigation

The two basic concepts proposed for this service are the following:

1. Transit bus-based systems to warn following driver(s) of potential collision (e.g., visual warning display on rear of bus);
2. Impact injury and damage mitigation systems

Tight Maneuvering/Precise Docking

This service will position the bus very precisely relative to the curb or loading platform. The driver will maneuver the bus into the loading area and then turn it over to automation. Sensors will continually determine the lateral distance to the curb, front and rear, and the longitudinal distance to the end of the bus loading area. The driver will be able to override the system at any time by operating brakes or steering, and will be expected to monitor the situation and take emergency action if necessary (for example, if a pedestrian steps in front of the bus). When the bus is properly docked, it will stop, open the doors and revert to manual control.

The safety element of this service cannot be understated. Pedestrian accidents are the most severe of transit accidents. The added functionality of a precise docking system, interfaced with a collision avoidance system, gives both drivers and pedestrians an added margin of safety. Also, safer boarding and egress for the handicapped, the elderly and children, are important considerations in developing these systems.

CHAPTER 5: TRANSIT IVI REVIEW- TECHNOLOGY

The purpose of this section is to review currently existing sensor technologies that could lend themselves to being used in a practical collision avoidance system. This section presents background information on the application of sensors to collision avoidance. Strengths and weaknesses of each type of sensor are discussed and recommendations made as to their suitability for employment as part of a collision avoidance system.

A Sensor as Part of a Collision Avoidance System

It is important to note that a sensor is only part of a collision avoidance system. The *sensor* (or multiple sensors) provides signals based on changes in the environment surrounding the vehicle. These signals are then interpreted by a *processor* that uses instructions contained in the system's logical *algorithms* to create a complete picture of the vehicle's surroundings from the limited information provided by the sensor. Finally, this processed information must be relayed to the driver through a suitable *display*.

The sensor is an important part of this system because it must reduce the wide variety of possible information received from the outside world to a meaningful flow of data that provides all of the needed information, and can be interpreted consistently by the other elements of the system. The type of signals generated by the sensor also dictate the logical process that the system's algorithms must carry out in order to interpret the information.

The ideal sensor, therefore, must have the following attributes:

- The ability to sense objects at a distance;
- The ability to be "directional" (to provide information on relative position);
- The ability to receive focused images;
- The ability to determine distance to surrounding objects;
- Compactness, durability, low-cost, and low-maintenance;
- The ability to work well in a system;
- The ability to provide information useful in a sophisticated system (such as imaging);
- The ability to distinguish between useful information and "clutter"; and,
- Low power requirements.

Unfortunately, no single sensor technology currently provides all of these attributes for all operating environments. Single sensor technologies can be used if a vehicle's operating environment will be confined. Otherwise, multiple technologies can be used to augment each other and provide accurate information in a wide variety of surroundings.

Sensor Properties

The following is an introduction to important concepts of sensor technology that will aid understanding of the various technologies, and consideration of appropriate uses.

Active vs. Passive Sensors

All candidate sensors can be divided into two categories: either active sensors or passive sensors. Active sensors send out a signal of the particular signal they detect, and then measure the reflected signal to determine position, proximity and other attributes of surrounding objects. An example of an active sensor is a police radar gun that emits a stream of radar waves in the direction that the gun is pointed, and can determine the speed of an approaching vehicle based on the reflected radar waves received back at the gun.

Passive systems, on the other hand, simply monitor ambient or naturally reflected quantities of the detected signal. The human eye is an example of a passive sensor that relies on reflected light from another source in order to function. If the lights are turned out, the eye cannot see. Many technologies support both active and passive use. For example, a flashlight used in low light conditions turns the eye/flashlight combination into an active sensor**.**

This is an important distinction because passive systems are usually less intrusive, less expensive, and simpler to use and maintain. However, unless the signal can be guaranteed to exist in all operating conditions, it is safer to supply a signal source. Also, active signals are more adept at measuring the distance and relative speed of objects, since they can calculate these quantities from the time it takes for the emitted signal to reach the object and return.

Imaging vs. Non-Imaging Sensors

Sensors can also be divided based on whether they are imaging or non-imaging. In general, an imaging sensor, as the name implies, is one that produces a geometrical image of the scene in the sensor’s field of view. While this image may not have the qualities of an optical image, it nevertheless possesses information about the positioning of objects within the field of view. For example, an imaging type sensor pointed at a test scene of two boxes separated by some distance (as shown in figure 21), would generate an information flow containing information about the positioning of two “objects” within the field of view. Depending on the type of information produced, it may or may not be possible to determine the range, separation, etc. Imaging sensors are, by their nature, highly directional.

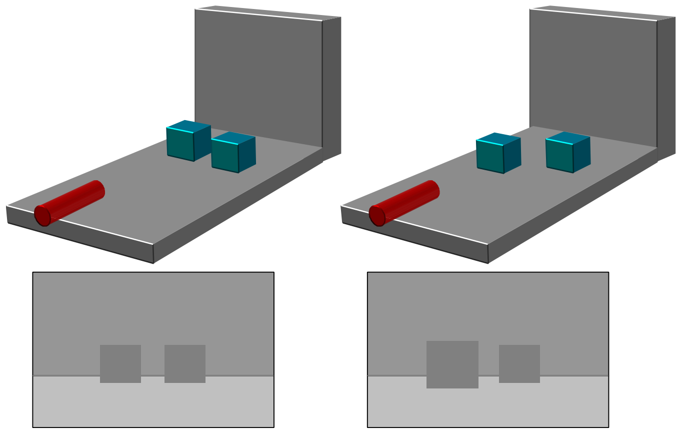


Figure 22. Two similar scenes. The sensor is represented by the cylinder and has the same position in each scene. The distance of the boxes from the sensor is equal in the left scene, different in the right.

A non-imaging sensor, on the other hand, is one that does not provide any spatial information as to the positioning of objects within its view. A non-imaging radar pointed at the test scene described above would produce only an "echo". If one of the boxes were removed from the scene, the same echo half as strong would be received. If the two boxes were at different distances from the receiver, two echoes of differing strength would be received at different times but no information concerning where in space each echo originated would be available other than that it was somewhere in the sensor's view. Non-imaging sensors are typically less directional that imaging types but can be made more directional through the use of multiple sensors, filters, and other methods. Police radar is an excellent example of a highly directional, non-imaging sensor system. The radar must be aimed manually at an oncoming vehicle and produces only an echo stating the speed of the fastest moving object in the field of view. In the event of multiple vehicles, the officer must determine which one is the speeder.

Imaging sensors provide much more information that supports more robust collision avoidance systems. These systems can better distinguish impending hazards from objects that are not threatening but happen to be close to the vehicle. Imaging sensors are also more expensive, however--ranging up to exponentially more expensive in some cases. This trade off must be weighed carefully when considering which technology is appropriate for a given application.

"Noise" and Clutter

Sensors detect specific types of signals from the outside world; for example, infrared sensors detect the heat energy given off by surrounding objects. Depending on the vehicle's surroundings, it is sometimes difficult to distinguish between meaningful signals--such as other vehicles or pedestrians that the vehicle may strike--and background signals—such as parked cars, roadside signs, or buildings. If care is not taken, this background "noise" can cause the collision avoidance system to falsely alert the driver that a collision is imminent. Needless to say, drivers will soon begin ignoring systems that are constantly “crying wolf”, which defeats the purpose of having the system in the first place.

Different sensor technologies are susceptible to “noise” to varying degrees depending on the surrounding environment. For example, an infrared sensor may be confused in an urban environment where hot pavement, and nearby buildings may give off as much thermal energy as pedestrians. However, on a rural highway the only concentrated sources of heat are likely to be other vehicles.

Alternative Sensor Technologies

A range of sensor technologies is available for use in a collision avoidance system. They operate on differing physical principals and are thus subject to different performance limitations. Currently, research is being focussed on six major technologies: radar sensors, ultrasonic sensors, optical sensors, infrared sensors, laser sensors, and electromagnetic sensors. These technologies can either be used individually, or combined into more complex systems that take advantage of each technology’s strongest attributes while mitigating individual shortcomings.

Radar

The principle behind radar is quite simple and has been refined to a high degree, since its introduction as a ranging system for aircraft in the 1930’s. A transmitter generates an electromagnetic signal at a given frequency in the radio or microwave region. This signal propagates at the speed of light ($3x10^8$ m/s) from the antenna outward as waves. When the outwardly propagating waves make contact with some object, they are reflected. The receiver then collects the reflected waves and the distance is calculated from the time of “flight”. Because the moving objects off which the waves reflect change the frequency of the reflected radar waves, relative speed can also be determined by measuring the change in frequency. More complex radar arrangements can also be used to determine the object’s relative position.

For use in a collision avoidance system, radar is perhaps the best overall choice based solely upon the physical properties. It is active and hence has the ability to perform ranging functions with much confidence. It is capable of being made to produce an image type product but typically has a lower resolution that other types of system so is in one sense less susceptible to noise. It can be made rugged, is relatively inexpensive, and has a high degree of operational reliability. Radar works well in day or night as well as in conditions of rain, fog, snow, and other vision limiting situations. It is also insensitive to the traveling speed of the vehicle. Finally, it can be incorporated in several different types of systems, either as an imaging or non-imaging sensor. For example, a single unit can be integrated into a simple proximity detection system that would simply detect whether or not an object is within a certain minimum distance. Several radar sensors can also be combined into a phased array radar system that can support much more advanced collision avoidance systems. These systems are, however, much more expensive.

Use of radar for collision avoidance has two major drawbacks: reflectivity "echoes", and atmospheric interference. Because radar emits electromagnetic waves in a wide beam, it can be fooled by stray reflections off of nearby buildings or other objects. In an urban environment, the wide variety of materials and shapes likely to be present could pose problems with reflectivity and cause radar to either fail to detect an obstruction or generate false alarms. The other limitation arises because, electromagnetic energy only travels uniformly through a vacuum; on or near the Earth's surface, the interaction of the radio waves and microwaves with the atmosphere become important. Large temperature gradients can exist between the area a few inches above the street, to the air several feet above the street. This difference in temperature translates to a large difference in density and therefore a significant difference in the speed of the signal between the hot and the cooler air. The net effect is to bend the path of the radar with unexpected results.

Ultrasonic

The use of sound waves to determine distance has much in common with radar. Both types of sensors make use of an emitter to generate a signal or "chirp" with regular, known characteristics, which then reflects off of an object and returns to a sensor for collection. The round-trip time of the signals are then measured and the distance to the object generating the reflection is determined. The primary difference between the two, is that sonar generates waves which transfer energy through some transmitting medium (usually either air or water), while radar uses electromagnetic waves which require no transmitting medium. Because of this, the quality of a propagating sound wave is strongly dependent upon the uniformity of the air through which it is moving. Precipitation can have a significant effect on propagation quality and limit the range of the sound energy. Large heat gradients in the air, such as those encountered in the first several feet of air near heated pavement, can cause sound energy to propagate non-uniformly and seem to bend in direction. This phenomenon is much more pronounced for sound than for electromagnetic energy such as radar.

In theory, an ultrasonic sensor would appear to be the ideal sensing element for a collision avoidance system: rugged, compact, and very low cost. In predictable geometry, low speed situations in which the distance being measured is relatively small, say less than ten feet, an ultrasonic sensor may be the technology of choice. An example of such an application is as use in a rear facing system to be used for collision avoidance when backing up. Clever applications of signal processing techniques and careful choice of transmission signals could extend the use of ultrasonic sensors into broader collision avoidance applications.

However, like the other sensor technologies, there are certain limitations and tradeoffs that must be considered. The medium through which sound propagates is highly variable in its state at different times. Changes in temperature and humidity can greatly affect the calculation of the range since the speed of sound is affected by these parameters. Sound travels much more quickly through warm air than through cold air for instance: 1088 ft/sec at 32º F, 1129 ft/sec at 68º F (a difference of nearly 10%) which directly affects the accuracy of the distance calculation. It is also significant that a substantial amount of ultrasonic energy is present in the urban environment and could lower the signal-to-noise ratio to below tolerable levels. This is a problem at high speeds as well since the interaction of the air with the surface features of a vehicle produces copious amounts of ultrasonic energy in the form of broadband “noise”. Finally, sound energy does not lend itself to a high level of directionality. Diffraction of sound energy, even short-wavelength ultrasonic energy, about objects has the potential to generate problems in such a system since filters and focusing elements are not very effective in producing directionality.

Optical

An optical sensor senses visible light. The eye is an optical sensor, and together with the brain forms an unparalleled system for detecting and classifying objects oriented in three-dimensional space. Electronic, imaging optical products abound, and the cost of the sensors continues to decrease drastically. Examples of this technology include VCR camcorders, digital cameras, and other video based communication systems. These sensors produce a 2-D image of the scene that is determined both by the sensor and the optical system that focuses the light from the scene.

The major advantage of optical sensors is the superior imaging quality of the information they convey. This information is also the easiest for the human brain to process directly. However, optical sensor have three main drawbacks: difficult automatic interpretation, lack of distance measurement, and a primarily passive-sensor nature.

First, current automatic classification technology is not able to reliably process optical information. Research into machine vision and related studies into artificial intelligence will no doubt improve the capability of target recognition and analysis of scenes by computers. However, this technology is still in its infancy and considerably more research and results in algorithms and software as well as further improvements in computer technology will be required before optically based collision avoidance technology becomes a practical alternative.

Second, optical systems are 2-D. That is, they produce a planar image of the field of view, which contains no easily obtainable depth information. Algorithms would have to be produced which could, from the information in the scene, determine the distance to objects in the scene. This could also perhaps be accomplished through the use of multiple cameras, which would produce a stereo image, or through use of a dual mode system, which would, in addition to the optical sensor, have a radar or sonar ranging sensor.

Third, optical sensors are passive devices that gather photons reflected from objects. Operation at night could pose problems as well as could adverse weather conditions. Supplemental lights could be added in an effort to extend the capabilities of these sensors but the practicality of adding large, side looking flood lights to transit buses is probably not realistic from either system or aesthetic considerations.

Infrared

This technology, based upon the properties of light having a frequency just shorter than visible, has several advantages over optical systems but shares some of its disadvantages. Infrared systems, like optical systems, are typically passive. However, unlike their visible counterparts, infrared systems do not rely on reflected ambient light for operation. Since all objects at a temperature above absolute zero radiate continually in the infrared region, no transmitter is needed even in low light conditions. In addition, both the human body and automobiles have large heat signatures. These properties are desirable in the development of an urban collision avoidance system since the primary obstructions to be avoided are pedestrians and other vehicles. Infra red sensors can be used in either an imaging or non-imaging applications.

A non-imaging option is to use large, single infrared detectors. In order to use these sensors to detect “objects”, several must be used and they must be employed with light filters and lenses so that their individual fields of view do not overlap. The signal from each element is then compared with the value of another sensor that looks at the background, usually the street. Any significant variations in the narrow field sensors, from the reference value, will trigger a warning. However, This configuration immediately poses problems in an urban setting. Because of frequent stops and an abundance of surrounding objects with different thermal properties, a uniform reference background may not exist.

The imaging option is called a focal plane array sensor. The advantage of a focal plane array is that an image is actually focused on the surface of the array and a digital image can be formed. This image can then be analyzed with sophisticated image processing algorithms similar to those under development for optical systems, which are extremely good at identifying particular features under some conditions. While being an excellent candidate for a collision avoidance system, an off-the-shelf array would be prohibitively expensive, since current infrared focal plane arrays sensitive to infrared light are made from exotic materials.

Infrared-based systems are much more subject to signal overload than are some other sensor types. Hot pavement on a summer day can easily exceed a temperature equal to or higher than objects to be avoided and fade the signatures of the people and cars into the background. Infrared sensors would also be highly sensitive to the thermal emissions of motor vehicle exhaust. Misclassification of hot exhaust as an eminent collision could reduce confidence in the system.

Also, as with an optical system, it is not possible to determine either range or range rate easily with either a low-cost sensor or focal plane array. With a focal plane array, shape and pattern matching techniques can be applied with limited success in determining distance based on comparing shapes (people, cars, etc.) with a library of shapes of known sizes. This can provide some crude range information but is problematic and slow. The prospect of ranging using a low cost, single element infrared sensor is simply not practical.

Laser

Similar to Radar, LiDAR (Light Distance and Ranging) uses an active LASER instead of a radio or microwave transmitter. This light is directed by the vehicle toward some obstacle and the reflected portion is used to determine the distance to that object. Using a LIDAR system, the distance to an object can be determined with incredible precision and accuracy. There is, however, one important difference between radar and laser; while the radar signal "spreads out" as it gets farther from the source, the laser beam has almost no dispersion. Because of this, a LIDAR is the ultimate in a directional, distance-sensing device. So directional in fact that its use is limited in a collision avoidance role where the location of the obstruction can be almost anywhere. A LIDAR with the transmitting LASER simply pointing in a single direction would be almost useless, as it would detect only those objects upon which it happened to fall. It would be akin to the driver of the bus, performing his job while looking through a pinhole.

Several possibilities exist for increasing the usefulness of LIDAR in a collision avoidance system. The first, and the simplest, would be to confine its use to fixed geometry situations: front and back collisions and backing up. Even here it is possible that the tightly focused beam of a LASER could miss the intended obstruction and provide no useful information.

Another possibility is to rapidly move the beam across some area in a predetermined pattern. In this way a coarse, depth image of the scene might be generated which could be used in detecting obstacles.

Finally, laser technology might be applied in the dual sensor mode, where a LIDAR is incorporated into an infrared system. The infrared sensor would detect the objects to which the LIDAR would then determine the distance. This is probably the most practical scheme in which a LASER would find application as it compliments the infrared sensor well. The main problems here would be in pointing the LASER in a meaningful direction.

Electromagnetic

While electromagnetic technology never been used in a collision avoidance system and is limited in its possible application, it perhaps bears investigation as a supplemental sensor. For the proximity sensor in practice, a small antenna generates a minute electric field about some point in space, in effect a transmitter which produces an electrostatic field. The state of the electric field in the absence of external objects is then set as the reference value. As an object moves closer to the antenna (particularly an object containing conductors but any type of object will have an effect), the strength of the electric field near the antenna will be altered. This change is detected using a sensitive meter. Using only a single antenna, a proximity sensor is basically non-directional. However, multiple antennas can lend some directional capability as can the electrostatic equivalent of baffles and lenses.

It is not realistic to expect that a proximity detector can be integrated into a collision avoidance system with the proximity detector as the only sensing element. However, perhaps the incorporation of such a detector into an infrared system could aid in the reduction of false alarms by incorporating an array of proximity sensors along with the array of infrared sensors. The proximity sensor, since it can be produced cheaply and reliably, might lend itself to being useful as an enhancement to other sensors.

Comparison of Sensor Technologies

The two tables below summarize how each technology compares to the "ideal" sensor. The first table shows all technologies used in a non-imaging role, while the second table shows the three technologies that can be imaging. A separate table is included because some of the properties of these sensor types are different in the imaging configuration.

	Radar	*Optical*	*Infrared*	*Laser*	*Ultrasonic*	*Electro.*
Type: active or passive	Active	both	both	active	active	active
Senses at a Distance?	Yes	yes	yes	yes	yes	yes
Directional?	Yes	yes	yes	yes	yes	no
Can be Focused?	Yes	no	no	yes	no	no
Ranging Information Available?	Yes	no	no	yes	yes	no*
Compact, durable, inexpensive?	yes	yes	yes	yes	yes	yes
Use in sophisticated system?	yes	yes	yes	no	no	no
Rejects clutter well?	yes	no	no	no	no	no
Draws Little Power?	yes	yes	yes	yes	yes	yes

Table 1. Summary of Sensor Technology Attributes for Non-Imaging Configuration

	Radar	Optical	Infrared
Type: active or passive	active	both	both
Senses at a Distance?	yes	yes	yes
Directional?	yes	yes	yes
Can be Focused?	yes	yes	yes
Ranging Information Available?	yes	no	no
Compact, durable?	yes	yes	no
Inexpensive (comparatively)?	no	yes	no
Rejects clutter well?	yes	no	no
Draws Little Power?	yes	yes	yes

Table 2. Summary of Sensor Technology Attributes for Imaging Configuration

From the tables, radar technology appears to be the best candidate for use in a single technology system, both as an imaging and non-imaging sensor. Infrared is also promising, particularly given the possibility of low cost infrared sensors to accomplish simple detection roles. However, when proper consideration is given to the urban operating environment of most transit busses, the situation becomes less cut-and-dry.

The urban setting is a high noise, high clutter environment for most sensor types. A typical side looking anti-collision system will have to contend with, and be able to differentiate among, many types of signals generated by many types of sources. Heat signatures, which are the energy source for infrared sensors, are very abundant in a city. Human bodies are small, generate heat, move about constantly in unpredictable ways, and occupy a range of heights. Automobiles, buildings, and other machinery possess significant heat signatures that vary depending on material, weather, and time of day. All these effects produce infrared signatures of varying intensities the net effect of which is to produce a very noisy and cluttered, infrared background.

Where radar is concerned, the urban environment is also cluttered in the radio frequency region though in a different way. Where the infrared "image" of the surrounding environment is strictly two-dimensional, the radar image of the background is three-dimensional. The wide variation in traffic spacing, building frontage, pedestrian location, and roadway related objects generate a multitude of depths and potential for confusion. In addition, a major problem for signal reflecting systems such as radar (and ultrasound as well) deals with "ghosting" phenomenon. This happens at close ranges, where a radar echo received may be more difficult to classify as a multi-path echo or a direct reflection. In addition, signs, curbs, and other stationary but non-threatening objects will add to the difficulty of developing robust collision avoidance systems.

Because the two strongest candidate technologies both have difficulty operating in an urban environment, no single technology is clearly preferred for transit bus collision avoidance systems. A combination of technologies will likely be necessary to ensure accurate and consistent detection. Some transit agencies that operate routes that only serve rural neighborhoods may be able to use a radar-only system. However, depending on fleet management, this may be too limiting.

Although no single technology emerges as the ultimate sensor type, the following points can help narrow the possibilities and focus research:

- Currently, the most promising option for a detection system that functions in complex environments is a combination of a sensor with strong imaging ability, and one with reliable range and speed determining ability. An example of this is an imaging infrared sensor that generates a 2-D "picture" of the vehicle's surroundings, and a pointed laser that double checks the "hot spots" to ensure that they are real and moving toward the vehicle before alerting the driver.

- Radar technology is currently the closest to development as a stand-alone sensor type. Further research into "ghosting" phenomena may eliminate this shortcoming and establish radar as the clearly optimal technology.

- Electromagnetic sensors deserve consideration as a low-cost secondary technology to help reduce the number of false alarms generated by a collision avoidance system.

- While infrared presents certain advantages to the other systems, it is unlikely that a low cost system using large LED-style elements such as those being produced by certain manufacturers would be highly robust as a stand-alone technology in a heat cluttered, urban environment. Even though transit agencies would be better able to pay for high-cost infrared phased array sensors, the benefits are dubious given the cost.

- Even though slower-moving busses are less prone to creating ultrasonic “noise” on their own, the air-dependant nature of current ultrasonic sensors makes them less desirable in a variable urban atmosphere. Further technological refinements, however, may make them a viable alternative for close-range sensors.

- Because busses are operated at night, through residential neighborhoods, where supplemental lighting is not an option, it is unlikely that solely optically-based collision avoidance systems will find their way onto buses in the near future. These technologies do have immediate usefulness on busses to augment driver vision during daytime hours or very close to the vehicle.

CHAPTER 6: CURRENT AND PROPOSED APPLICATIONS AND RELATED PROJECTS

This section of the report is intended to lay out current and proposed projects that will have an impact on the information available about IVI applications. It is important that any "lessons learned" from these projects be made available to the transit industry. As many previous high technology studies have indicated, the transit industry is reluctant to implement untried, untested technologies into its basic fleet operation. The very relevant concerns about cost and credibility require that transit be as informed as possible on all applications that might be useful in their operations, while best utilizing taxpayer resources across the transportation field. Much can be learned from existing, ongoing and proposed projects being undertaken by other platforms. In particular, quite a bit of research had been completed in the areas of collision avoidance systems for light vehicles. A prudent use of public funds would be to capitalize on other platform research and development, and build upon already existing findings, by examining them in a transit specific environment.

The projects are listed below, indicating partners and a brief description of each project.

Performance Specifications for Rear Collision Mitigation

Partners: USDOT/Federal Transit Administration (FTA)
California PATH Program, University of California at Berkeley
Robotics Institute, Carnegie Mellon University
Texas Transportation Institute, Texas A&M University

One of the most frequent accidents in transit bus operation is when a vehicle collides with a bus from behind. The basic premise is built around corrective measures that will mitigate the consequences of rear collisions. In addressing the primary factors that cause rear collisions, one key issue is to develop a warning system that can provide a longer time window for the drivers behind the bus to observe and react. If a driver is given an effective warning signal and sufficient time to react, the frequency and the severity of accidents can be lowered. Research, development, and deployment in the area of rear impact mitigation can leverage off existing sensor technologies and prior research completed for warning systems in other domains. But, in order for the system to be truly successful, several unique technical issues specific to rear impact mitigation must be understood and addressed. The most significant of these are sensor requirements, warning criteria and false alarms, and warning modality.

Rear collision warning is a relatively unexplored area. Because the historical accident data do not normally contain detailed information on major causes and circumstances of bus rear-end collisions, it is necessary to collect real world data in order to characterize the behaviors of drivers behind buses as related to the bus maneuvers. Milestones will be set to review the cost benefit of the proposed countermeasures based on the period of data collection. The knowledge gained through the data collection and analysis in the first year will also be used to further define the scope of work for the system development and testing in the second year.

The final product of this work is the generation of performance specifications, including functional level and component level specifications for rear-collision warning systems. The results from the analysis of data acquired during the development of the system and the validation tests will be summarized in the final report along with the performance specifications.

Performance Specifications for Frontal Collision Warning System

Partners: USDOT/Federal Transit Administration (FTA)
San Mateo County Transit District (SamTrans)
California Department of Transportation (Caltrans)
University of California PATH Program
Gillig Corporation

SamTrans operates a fleet of 316 buses in one of the most congested areas in the country, which includes the counties of San Mateo, Santa Clara, and San Francisco. A frontal collision warning system using advanced sensing and computer technologies can increase safety by giving advanced warning to the driver about potential hazards. Furthermore, information collected through sensors can be recorded for the purpose of accident analysis and for avoiding false claims.

SamTrans will be establishing a framework to implement such warning systems. Caltrans has been a leading agency coordinating development of advanced technologies for transportation industries, and is responsible for traffic control on El Camino Real, one of the main corridors in SamTrans' operational region. Caltrans will be implementing collision warning and avoidance technologies on transit and other vehicles to improve traffic operations and decrease congestion. Gillig Corporation will participate in the development of new technologies and the proof-of-feasibility testing to gain experience in implementing them on future transit buses. California PATH, a world-wide leader in the development of advanced vehicle sensing and control systems, will add its expertise to collision warning systems for transit buses and widen its reach into ground transportation vehicle systems.

A Regional Advisory Committee has been formed for this project from select transit agencies within the greater Bay Area, with the purpose to facilitate communications among the transit community, and contribute to early development of a CWS market. These representatives will assemble to review and provide input on the development of the CWS. Periodically, the committee will be convened by SamTrans to receive reports and updates from representatives of PATH, Caltrans, and Gillig Corporation.

The goals of the collision warning systems for this project are to (a) address imminent crash warning, (b) provide warnings for smoother maneuvering, (c) provide warnings when bus is too close to a forward vehicle. (A) is the primary goal, with the other two being secondary.

Performance Specifications for a Next Generation Side Collision Warning System

Partners: UDOT/Federal Transit Administration (FTA)
Carnegie Mellon University (CMU)
Pennsylvania Department of Transportation (PennDOT)

This project is building on completed and on going NHTSA efforts to develop performance specifications for lane change and merging collision avoidance systems (LCMCAS). NHTSA performance specification projects have focused primarily on light vehicles. This project addresses collision countermeasure systems for transit bus vehicles. Performance specifications for transit bus LCMCAS will be developed by leveraging data, methods, technologies, and results from earlier NHTSA tasks and completing new tasks as appropriate.

A large fraction (but not all) of NHTSA LCM performance specification work is applicable to transit buses. Additional new work is necessary for transit bus systems due to differences in vehicle characteristics, the operating environment, and driver capabilities compared with light vehicles

Sensor Friendly Vehicle Roadways

Partners: USDOT/National Highway Traffic Safety Administration (NHTSA)
Bechtel
Carnegie Mellen University (CMU)
UC/PATH
Caltrans
PennDOT

This project is focused to develop and test vehicle and roadside cooperative markings and features which can be easily and rapidly deployed, and which significantly enhance the performance of otherwise autonomous IVI systems. It will evaluate what can be done with the infrastructure to optimize the performance of the vehicular sensor.

Evaluation of Delco/GM Rear-End Collision Countermeasures

Partners: USDOT/National Highway Traffic Safety Administration (NHTSA)
USDOT/Research and Special Programs Administration/Volpe National Transportation Systems Center (Volpe Center)

NHTSA has entered into a cooperative agreement, entitled "Automotive Collision Avoidance Systems Field Operational Test", with a private consortium (Consortium) consisting primarily of Delco Delphi and General Motors (GM) corporations. The focus of this joint effort is to conduct research activities that investigate vehicle-based rear-end collision countermeasure systems.

This project will conduct a field operational test that demonstrates state-of-the-art rear-end collision warning systems, leveraging the experience, know-how, and technologies developed in a prior NHTSA-sponsored research program known as the Automotive Collision Avoidance System Development Program. The Volpe Center will be responsible for the independent evaluation of this field operational test by assessing the safety impact and benefits, driver acceptance, and performance of these rear-end collision warning systems.

Moreover, the Volpe Center will cooperate with the Consortium and, particularly, with the University of Michigan Transportation Research Institute (UMTRI) who will design and conduct the field operational test, so as to identify feasible data collection protocols and to ensure the proper collection and delivery of test data. In addition, the Volpe Center will work closely with other organizations such as NHTSA's Vehicle Research Test Center (VRTC) and Johns Hopkins Applied Physics Laboratory (APL) to conduct independent experiments in support of the evaluation of the field operational test.

Development of Collision Avoidance Data for Light Vehicles

Partners: USDOT/National Highway Traffic Safety Administration (NHTSA)
USDOT/Research and Special Programs Administration/Volpe National Transportation Systems Center (Volpe Center)

The Volpe Center will provide technical support to the light-vehicle platform within the IVI. This support will enhance the collision avoidance knowledge base by providing collision avoidance data and tools essential for estimating the benefits and establishing performance specifications and objective test procedures for light-vehicle IVI safety systems. The collision avoidance data will include detailed description of collision types and pre-crash scenarios, driver and vehicle performance data, and roadway, vehicle fleet, and driving exposure statistics. Collision-related information will be obtained from detailed assessment and analysis of national crash databases, namely the General Estimates System (GES), the Crashworthiness Data System (CDS), and the Fatality Analysis Reporting System (FARS). Driver/vehicle performance data will be retrieved from USDOT sponsored studies related to the light-vehicle platform, based on limited and controlled tests on traffic roads, test tracks, and in driving simulators. Roadway, vehicle fleet, and driving exposure statistics will be compiled from available public and private information sources. In addition to the collision avoidance data, relevant benefits estimation methodologies and tools will be modified and applied to specifically address the safety benefits of the light-vehicle platform. The primary focus of this benefit assessment will be on the safety benefits estimation methodology already developed by the National Highway Traffic Safety Administration (NHTSA) and on the methodologies and tools currently under development within the crosscutting activities of the IVI program.

Benefit Assessment of Intelligent Vehicles

Partners: USDOT/National Highway Traffic Safety Administration (NHTSA)

USDOT/Research and Special Programs Administration/Volpe National Transportation Systems Center (Volpe Center)

The deployment of integrated IVI products and services in all platforms of the vehicle fleet has the potential to bring to motorists, the surface transportation system, and industry numerous benefits in safety, convenience and comfort, mobility, efficiency, productivity, and the environment. The Volpe Center will assist the USDOT in the development of proper methodologies for estimating the effectiveness and potential benefits of IVI systems. The safety benefits of IVI products and services are the primary focus for this project; other benefits in mobility, efficiency, productivity, and the environment will also be addressed as necessary. The availability of these benefit assessment methodologies ensures that appropriate data needs are conveyed to field operational tests which, in turn, collect and provide data that will enable both the USDOT and industry to assess the benefits of individual and integrated IVI products and services; and subsequently, to prioritize their research, development, and deployment efforts.

Review of Societal and Institutional Factors for the Intelligent Vehicle Initiative

Partners: USDOT/National Highway Traffic Safety Administration (NHTSA)
Parsons Brinkerhoff

Some respondents to the IVI Request for Information noted their concerns with the impacts of IVI services on society and noted potential barriers to deployment, including the general areas of product liability and the institutional challenges of enhancing the roadway infrastructure to better support intelligent vehicles. Driving assistance and control intervention will lead to changes in drivers' responsibilities and actions. To properly interpret the results of IVI field tests across the four platforms, the likely interactions between IVI systems and the society and environment in which they will function must be understood. Experience with previous vehicle highway automation projects emphasized the value of identifying these issues early in the program and finding constructive and realistic solutions so that key stakeholders can accept the program.

The objectives of this project are to identify impacts of the deployment of IVI services on society, from the differing perspectives of motorists in IVI compatible vehicles, other motorists, other transportation stakeholders, and on the transportation system itself. Impacts associated with early deployments of IVI services, such as those selected for field testing, will be a particular focus. It will also define specific barriers to deployment of vehicles with IVI services and recommend alternative solutions that will reduce or eliminate these barriers. These barriers will, at the minimum, include (1) product liability; and (2) changes to vehicle insurance coverage to recognize the effects of intelligent vehicle warning and partial control services. Lastly, it will identify critical issues and analyze the role of transportation system infrastructure providers, including private, state, and local agencies, to determine their capability, their motivation and acceptance, the likely timeframe, and critical economic requirements that will affect the provision and maintenance of roadway systems and improvements needed to support IVI.

Automation of Driver Controls

Partners: Houston METRO
Carnegie Mellon University (CMU)
National Automated Highway Safety Consortium (NAHSC)

The Metropolitan Transit Authority of Harris County (METRO) in Houston, Texas has taken the lead in the testing and demonstration of automated highway systems in transit applications. In 1997, METRO represented the transit industry in the NAHSC Demonstration '97 in San Diego, CA. Following Demo'97, METRO sponsored a smaller, transit-focused demonstration in Houston. METRO supposition was that IVI could benefit transit agencies by reducing operational costs, increasing commuter throughput and improving passenger safety.

For four days in August 1997, passengers aboard two automated METRO buses rode along a stretch of dedicated HOV lane. This proof of technical feasibility demonstration featured full-scale, multi-vehicle demonstrations of automated highway system (AHS) technologies. The 1997 AHS Demo had seven scenarios. Designed to showcase different technologies and different functions:

- Platoons, with closely-spaced vehicles following buried magnets
- Free agents, with cars and buses using vision and radar
- Evolutionary, showing how this technology can be introduced incrementally for driver assistance
- Control transition, using both vision and buried magnets
- Alternative technology, using a radar-reflective strip for lateral control
- Infrastructure diagnostic, checking the accuracy of the magnets
- Heavy trucking, using radars for smart cruise control and driver warning

Houston METRO, in concert with Carnegie Mellon University (CMU), built one of the seven demonstration scenarios, the Free Agent Demonstration (FAD). The ability to run by independently is the reason they were called "free agent". METRO's 40 foot, low floor buses were outfitted by CMU with the hardware and software necessary for automated steering, braking, headway maintenance and collision avoidance. The retrofit took four months to complete. Much of the underlying technology was new, built specifically for the Demo. Other components were adapted from previous work. The FAD involved two fully automated cars, one partially automated car and two fully automated New Flyer 40-foot transit buses. The scenario demonstrated lane entry, speed and headway control, lane following, lane changing, obstacle detection and cooperative maneuvers. A second smaller demonstration was held the following December on a five mile stretch on one of the Houston HOV lanes.

The philosophy behind the free agent scenario was to surround the vehicles with sensors, putting all the sensing and decision-making on board the vehicle. When the vehicles see other automated vehicles, they can communicate with them and drive close to each other. But they also have enough perception and reasoning that they operate autonomously, mixed in with conventional, manually driven vehicles.

Results: All runs proceeded safely. During the development, a few minor bugs were found and fixed. i.e. radios that worked for the testing in Pittsburgh and Ohio did not work in San Diego; new digital radios were used. For the actual runs, each vehicle followed script, designed to showcases all the desired functions. The script was also used to turn on and of obstacle detection: early test showed that the radars would pick up overpasses as obstacles, and incorrectly slow the vehicles until the roadway began to dip down and the radar pattern fell below the level of the bridge.

Potential Benefits for Transit: METRO has identified IVI technology as having potential for future application to the region's HOV lane network as a cost-effective means of increasing vehicle throughput, reducing operational costs and improving passenger safety. These technologies would allow buses to automatically ride down a Houston HOV lane before heading off to other destinations. Because the buses could be spaced close together, the capacity of the HOV lane would be increased. IVI systems would also allow buses to run in both directions on the HOV lane, again increasing capacity on what is now a one-directional transit lane.

This project has been completed. It was designed as a demonstration project to accommodate a specific need under the AHS program, but does have implications for the IVI program.

Collision Avoidance Field Test

Partners: USDOT/National Highway Traffic Safety Administration (NHTSA)
GM
Delphi Delco Electronics Systems
The University of Michigan Transportation Research Institute (UMTRI)
The Volpe National Transportation Systems Center, Cambridge, MA

The partners have announced a multi-million dollar field operation test of a rear-end collision avoidance warning system. The test will evaluate performance, benefits and safety systems using "real cars, on real road with real people". It will create prototype crash-warning systems that caution drivers about potential hazards ahead of them by means of audible tones and visual displays. This is the first of the IVI operational tests to be announced and is expected to run for five years. The first half of the five-year project will involve pre-development of prototype vehicles equipped with crash avoidance technology. The second half will include field-testing of the prototypes and involve more than 100 licensed drivers from Michigan.

The research will be conducted at GM facilities in Warren, Michigan, along with Delphi Delco facilities in Kokomo, Indiana, and Malibu, California. The University of Michigan Transportation Research Institute will manage the field-testing and the Volpe Center in Cambridge, MA will analyze the field data.

CHAPTER 7: TRANSIT INDUSTRY ATTITUDES

Outreach Session Breakouts

Breakout sessions held at the Transit IVI Forum and Roundtable in Houston Texas, in December of 1997 focused on five topic areas: Operational, Technology, Maintenance/Maintainability, Human Factors and Training. Outputs from the breakout groups were as follows:

Operational

Key operational issues associated with the implementation of IVI are:

- Safety - vehicles impacting buses on the surface street and freeway, pedestrians being hit, and warning systems needed with sensitivity as a key factor.
- Cost - justification, life cycle, risk avoidance and accident liability
- Maintenance - eliminating idling, reduction in fuel emissions, better facility throughput, remote ignition and automated data download for maintenance processing
- Efficiency - closer headway operations, precision docking, vehicle diagnostics, on-time performance, and bus/rail schedule integration

Impacts included: workload of employees in maintenance, as well as driver impact. Obviously, the overriding concern was one of not adding an extra burden on the transit employee, while attempting to utilize new technology.

Early involvement of union representation and throughout the implementation process was another area of concern for the industry.

In terms of costs to operators and manufacturers - In essence, program technology and feasibility and pre-existing resources will determine the overall program costs.

Technology

The industry group was asked to address major technology areas for IVI and identify those that are roadside based and those that are in-vehicle based. Also, participants were asked to list technology areas in descending order of appearance.

Major technologies were broken down into two groups: in-vehicle and roadside based. The group dealt mostly with in-vehicle based technologies because they were more immediate and will be available in the short-term (1-5 years). The five major areas were as follows:

Guidance:	radar, mechanical, magnetic, wire, sonar, differential global positioning system (DGPS), adaptive cruise control/adaptive vehicle control/warning technologies

Vehicle:	separate data channel for information communicating to control center from vehicle, sensor systems, braking/stopping systems
Vehicle Diagnostics:	in yard guidance, rail using in yard, wire/robot
Security:	video/audio, alarm systems (silent and non-silent), video/audio next bus information
Customer Information:	fare validation systems, next bus, emergency messaging (video/audio)

The role of government vs. industry was also addressed. The role of the government should be one of guidance and program direction, as well as, needs determination. The private industry role should be more traditional in manufacturing and development, deployment. And lastly, the transit agencies themselves should articulate the needs and desires of the transit industry.

The group expressed the importance and uniqueness of the existing transit infrastructure. Any deployment of new technologies should be synergistic with existing infrastructure, thus eliminating the need to create new infrastructure accouterments. And emphasis must be placed upon cost effectiveness and return of capital investments. This is a critical and pivotal point for the determination of new and enhanced service provisions for transit providers.

Integration is also a key point and builds upon the desire to utilize existing infrastructure in a costly manner. The driver must be involved and in command of whatever system is deployed. Existing resources must be integratable, and ready to be replaced. In other words, not just replaced for the sake of creating a new device.

And, lastly, within the area of integration, patent rights and other proprietary issues were discussed. The upshot of these discussions was that it should be market driven and traditional. And, when there is dispute over ownership and proprietary disagreement, the government is final arbitrator.

Maintenance and Maintainability

The following is a list of issues in ranking order with some considerations for each:

Cost:	reduction and effective operations
Customer Service/Reliability:	immature technology, warranty, quality, tamper free/detection, safety, revenue
Personnel:	labor, training reallocation of resources, cultural shifts
Technology:	interfaces, protocol, testing, internal/external, intermodal, user friendliness, modularization, diagnostics

Policy:	fleet age and size, extended warranty, capitalization and contracting structure

The transit industry's maintenance and maintainability is also applicable to IVI technology and is currently at the highest level in the organization because the industry is attempting to maintain service, work efficiently and achieve maximum utilization of personnel. The issue at hand relates to integrating this ethic with new technology implementation. As technology is introduced into the systems, transit must be ready to change physically and programmatically. A potential role for the National Program Manager may be to assist in the development of standards and interfaces for the new technology and implementation.

Human Factors

Human Factors issues impacting IVI technologies are:

User Acceptance:	acclamation, education/training, resistance to change
Driver/System Functionality:	self check procedures, warning systems for resumption, dual use technologies and applications
Driver Distraction:	limitations due to other duties, limitations on current duties
Agency Culture:	promulgation and implementation of guidelines
Operator Stress:	over reliance on technology, sensory overload, confidence level, adaptation to different vehicles
Workstation Layout:	agency needs, driver adaptability and ease of operation
Rider Perception:	education of public, confidence building

A technical approach to human factors is key to the success of IVI technology deployment in the transit industry. The IVI program needs to advance technologies through the process of technical studies, prototype development, operational testing and evaluation, and market research, all within the arena of human factors. The issue extends well beyond driver interface, as it is a public service and requires rider acceptance as well. Beyond the technical issues lies the critical buy-in and acceptance that is necessary from the operators, and their union representatives. Educating the union on IVI technologies as enhancements to drivers jobs will be a very important and necessary first step, utilizing contract-mandated training as an opportunity to show drivers they can increase their levels of excellence with IVI.

Training

With the implementation of IVI technologies, there are several training issues. The industry was queried to address training issues and specific technologies. Clearly, every technology application has training issues, especially when these involve moving the public in a safe and efficient manner. Before training needs can be determined, human factors, system and technological needs must be established. With that said, the results are as follows:

Technology Comprehension:	individual safety, job security, on-time performance, role of operator
Operations:	provider of transit service, standards, common interface with driver, human factors impact, driver confidence
Operator :	warning recognition, response, prioritization of warnings (protocol)

The implementation of IVI will generate new requirements for training programs. There will be a new process and a new audience. According to the industry focus group, the methods for training will be classroom, on-board, simulation, self-paced study/Internet based, and train the trainer. Maintenance staff will be trained, as well as operators. Training will be more complex due to the diversity of components and the diagnostic capabilities of the workforce, and al will lead to compensation shifts. Those affected by the technology shift will include: boards of directors, supervisors, managers, dispatchers, information managers and relayers, procurement and acquisition, engineering staff, safety and security, counsel, risk management, and human resources. In essence, affected audience is all encompassing to the transit agency.
In terms of prioritization of training needs, the focus group was quite clear:

- Awareness
- Outreach
- Standard Operating Procedures
- Service Personnel (operations, maintenance, dispatch, supervision)

This group, along with the others was also asked to define the role of government vs. private industry. In essence, the government should manage the adaptation of model training programs for each location - - centralized development. The government should also lead the development of guidelines (supervision, operations, maintenance, etc.). The role of industry is in the area of training development. In particular, bus manufacturers were held out as having a distinct role in new technology acceptance and training upon delivery.

Also of note in the training discussion is that the focus group emphasized the need to address other Intelligent Transportation Systems and integration and education. The group felt strongly that one couldn’t be separated from the other. When addressing IVI training and development initiatives, other ITS initiatives, such as Advance Public Transportation Systems (APTS) must be incorporated and integrated.

Request for Information Response Overview

In December of 1997, the USDOT issued a Request for Information (RFI). Contained in the RFI were the anticipated focus areas for each platform. The purpose of the RFI was to allow the transportation community to offer comment on this DOT initiative. Responses were solicited and received by DOT's Joint Programs Office (JPO). ITS America was asked to assist DOT in reviewing and analyzing the responses. The majority of respondents were vehicle manufacturers, freight carriers, and state government (infrastructure providers). Responses from the transit industry were not as extensive as anticipated; and no input was received from insurance companies. The general comments that could apply to transit were as follows, with respondent in parentheses:

- Strong recommendation to prioritize user services (Battelle, Toyota, others).
- Select only a few high payoff user services for early investment and action (Battelle, Toyota)
- Many platform specific services can also be useful on other/all platforms (several)
- Fully automated driving on dedicated facilities could be implemented more rapidly and easily. In many cases the partial or temporary control poses more difficult problems than complete automation on dedicated facilities. (PATH)

Comments regarding the transit operational mode are as follows:

- Bus Rapid Transit on existing surface streets, enabling rail-type efficiencies without disruptions and inflexibility of guideways (LA Metro)
- Fully automated transit maintenance facilities (Houston)[18]
- Fully automated HOV (Houston)

Due to the less than expected transit participation in the RFI, a set of user services surveys were conducted at the two IVI Meetings held in Houston and Salt Lake City. Both surveys had similar results. Results of the first survey indicated that the top three services (not specific to transit) that should be emphasized are real-time traffic and traveler information, transit passenger information, and rear impact, respectively.

A second survey was conducted to determine which user services were most germane to the transit industry. The results indicated that the top four services of preference were: lane change and merge collision avoidance, rear end collision avoidance, precision docking, and rear impact mitigation, respectively. As a result of a final query of the participants, user services were prioritized as follows:

---

18 *RFI Response Overview*. Bihop, P. 1.

User Services	Number of Votes
Lane Changing and Merge Collision Avoidance	13
Rear End Collisions Avoidance	8
Precision Docking	7
Rear Impact Mitigation	7
Lateral Control	4
Intersection Collision Avoidance	3
Fully Automated Control at Facilities	3
Railroad Crossing Collision Avoidance	2
Vehicle Diagnostics	2
Automated Transactions	1
Safety Event Recorder	1
Obstacle/Pedestrian Detection	1
Low Friction Warning and Control Assist	1
Passenger Mishaps	1
Jostling in Bus	1
Backing Collision	1
Road Departure Collision Avoidance	0
Vision Enhancements	0
Location Specific Alert and Warning	0
Automatic Collision Notification	0
Smart Restraints and Occupant Protection	0
Navigation Routing	0
Real Time Traffic and Traveler Information	0
Driver Comfort and Convenience	0
Vehicle Stability Warning and Assistance	0
Driver Condition Warning	0
Cargo Identification	0
Transit Passenger Monitoring	0
Transit Passenger Information	0
Longitudinal Control	0

Attitudes in the Transit Community Towards AVCS

Lessons learned from the study of Advanced Vehicle Control Systems in Public Transportation Systems are germane to the IVI Needs Assessment process. A few of the salient points are:

- The transit industry is forced to be more conservative and cost conscious, due to a limited amount of funding, especially for R&D efforts.

- "Transit managers cannot afford to be adventurous, either from a cost or operations standpoint, because there is little or no funding available for experimentation, and a system failure is unacceptable to the riders who rely on the service. "[19]

- There tends to be a reluctance to "be the first", or to be the test ground in the public arena.

- "A transit consultant…who unsuccessfully lobbied for the deployment of a guided busway to connect the airport and ship port area found decision makers to be unreceptive to the new technology, with their attitude being that other transit properties would already have deployed such systems if they were cost-effective and reliable."[20]

There is a perception in the transit industry that deployment of new technologies, especially those that are not the traditional cutting edge (information flow-oriented i.e., real-time fleet management and traveler information services) being high risk. Also, there is a distinct reluctance to be the first. Each would like to see another be the real life test case. "I like to be the second guy to adopt new technology, but not the first."[21]

Although the feedback was specific to AVCS, it is acceptable to assume that these attitudes apply to the application of IVI technology. There is a very real fear of system failure, and an expectation of 100% reliability. Although this appears to be an unrealistic goal, when put in the context of moving revenue passengers safely, it is a legitimate goal.

When assessing the transit industry attitudes towards new technologies deployment, one must take into account the bus manufacturing industry, both domestic and international. Bus manufacturing industry interest is critical. Once again, in assessing the AVCS, the following was noted:

- "This may be a challenge because the level of R&D funding is typically very low in the bus industry and manufacturers would need to see a strong demand from their customers to justify any exploration…"[22]

- Transit bus manufacturing is a customer driven industry, with little resources or desire to develop new technology applications. "Several European bus manufacturers,

---

19 Opportunities for Advanced Vehicle Control Systems in Commercial Vehicle Operations and Public Transportation Systems; Federal Highway Administration; 1997; P. 10..
20 Ibid.
21 Ibid.
22 Ibid.

however, have proven their interest in vehicle control technology by deploying guided buses and investing in guidance technology."[23] Domestic manufacturers may follow suit.

23 Ibid.

CHAPTER 8: PRIORITIZATION OF TRANSIT IVI APPLICATIONS FOR DEVELOPMENT & CONCLUSION

Based on the outputs of the previous tasks, the Transit IVI applications worthy of further research and development under the Transit IVI Program have been prioritized. Issues of concern, specific areas on which to concentrate, or place less emphasis, and additional studies required have been identified.

In prioritizing the IVI applications, the first and most important factor must be safety. With this in mind, and based upon the baseline statistics, applications should be prioritized as follows:

Lane Change/Merge Collision Warning and Avoidance
Rear Impact Mitigation
Forward Collision Warning and Avoidance
Tight Maneuvering and Precision Docking.

In terms of future needs and demographics, the same holds true as the riding public ages and ridership with disabilities may be increasing. Thus, the priorities remain the same with the inclusion of another element of pedestrian and object detection. Also, increased urban sprawl and more complicated trips warrant the addition of automated controls. Thus,

Lane Change/Merge Collision Warning and Avoidance
Rear Impact Mitigation
Forward Collision Warning and Avoidance
Tight Maneuvering and Precision Docking
Pedestrian and Object Detection
Automated Controls

Next, taking into account industry attitudes and user services preferences, the list remains the same with heavy emphasis placed upon rear impact mitigation. Therefore, a slight rearrangement of the list’s priorities:

Rear Impact Mitigation
Lane Change/Merge Collision Warning and Avoidance
Forward Collision Warning and Avoidance
Tight Maneuvering and Precision Docking
Pedestrian and Object Detection
Automated Controls

This logic and approach also capitalizes on the maturity of various technologies, and on already developing technologies in other platform applications.

CHAPTER 9: ISSUES OF CONCERN

There are several issues of concern that have arisen as a result of the Needs Assessment. Some are outlined below:

Industry buy-in is critical. Buy-in must be at every level, and across the strata. It is as important for the bus manufacturers to be on board, as it is for the bus drivers. These applications will have systemic implications, and need system/industry-wide support.

The data available to support the IVI program is, at best, adequate. New data gathering, which is transit specific, and detailed to the level of the GES data is sorely needed. Although some assumptions can be made, and the GES appears to approximately mirror transit data, it does include inter-city buses. Better, and more "real life" data gathering and analysis cannot be ignored. Each project should have a data-gathering requirement. A perfect hybrid would be transit-specific GES with reliable property damage.

In general, this assessment was difficult to accomplish, as there was very little hard data available to apply to the transit program. In particular, cost data on technologies was, for the most part unavailable or estimated for light vehicles. When placed in a highly cluttered urban environment, on a low technology conventional transit bus, with an average age of 8.5 years, the dynamics change drastically. Therefore, a cost benefit analysis is almost impossible to predict. A good cost/benefit analysis needs harder, more quantitative data, (cost, OEM, fatalities, injuries, etc.). Once the data is collected as part of each project specification, individual cost benefit studies should be attached.

Safety is a primary concern to both DOT and the transit industry. But for the transit community, revenue and operating funds are also critical. Efficiency is a motivating force. There needs to be greater emphasis placed upon efficiency and mobility. What may make it attractive to the transit industry are the cost savings to the operating revenue. First, "Even the most pro-technology transit property will require a compelling economic analysis of the costs and benefits of an unproved technology approach…"[24] Second, labor typically represents 75% of operating costs, therefore, any assistance in reducing costs will benefit the industry. But there is still the issue of the highly unionized transit industry, and the fear of job loss that must be overcome. This also harks back to the early point about buy-in.

The transit platform should work smart, and build upon existing and prior technology development. Testing should be in a transit specific revenue-operating environment. Build upon already instituted projects (i.e. NHTSA LCMS and Rear End CAS, Truck Precision Docking) and apply to the transit bus. This cuts down on costs, but adds to the ease of public transit managers.

---

24 Opportunities for Advanced Vehicle Control Systems in Commercial Vehicle Operations and Public Transportation Systems; P. 11.

Support research of ITS economics and use of existing infrastructure. Low investment, high pay off. Transit is a ready-made environment with an existing, costly infrastructure. Potential IVI applications should take into account the utilization of existing infrastructure.

Following suit with the previous bullet, is integration and interoperability. Thought should be given to interoperability with existing initiatives, such as APTS and Bus Rapid Transit, as well as other government sponsored technology applications.

And, last, as with any other ITS initiative, deployment… for public transit will encounter more significant institutional and legal hurdles than technical challenges."[25] Thus, industry education, communication and information exchange between the bus manufacturing community, the transit system personnel, the component manufacturers, government and other stakeholders will be key to the success of the program.

25 Ibid; P16.

REFERENCES

1. American Public Transit Association, *Mobility for the 21st Century: A Blueprint for the Future*. Mobility for the 21st Century Task Force and Robert L. Olson, Institute for Alternative Futures. Washington, DC, October 1996.
2. American Public Transit Association, *Strategic Goals for the 21st Century: A* Report of the Mobility for the 21st Century Task Force of the American Public Transit Association in Cooperation with Institute for Alternative Futures. Washington, DC, October 1996.
3. American Public Transit Association, Transit Fact Book. APTA, Washington, DC, February 1998.
4. Apogee Research, Inc., Wilbur Smith Associates. *ITS National Investment and Market Analysis.* May 1997.
5. D. Gruen and L. Burke, The Intelligent Vehicle Initiative: Potential Applications to Various Areas within the Transit Arena. USDOT/Volpe Center, Cambridge, MA, November 1998.
6. J. Hopkins and R. Larson, Opportunities for Advanced Vehicle Control Systems in Commercial Vehicle Operations and Public Transportation Systems. U. S. DOT, Report No. FHWA-RD-96-139, January 1997.
7. L. Blincoe. Telephone Interview. U.S. Department of Transportation. National Highway Traffic Safety Administration, Plans and Policy, Washington, DC, May 10, 1999
8. L. Blincoe. The Economic Cost of Motor Vehicle Crashes. DOT HS 808 425, 1994.
9. L. Burke, Transit Intelligent Vehicle Initiative (IVI) Baseline Statistics Report, USDOT/Volpe Center, Cambridge, MA, March 1999.
10. L M. Roche, *Economic Costs of Occupational Injury Fatalities in New Jersey in 1992.*Occupational Health Service, New Jersey Department of Health, Trenton, NJ, 1992.
11. National Safety Council. *Accident Facts1996 Edition*.Itasca, IL, 1996.
12. National Safety Council. *Accident Facts1997 Edition*. Itasca, IL, 1997.
13. National Safety Council. *Accident Facts1998 Edition*. Itasca, IL, 1998.
14. *National Automotive Sampling System, General Estimates System*. U. S. Department of Transportation. NHTSA. Data years: 1994, 1995, and 1996.
15. Pennsylvania Department of Transportation. *A Summary of Commercially Available Side Collision Warning Systems*. AssistWare Technology, 1998.

16. R. Bishop, *IVI RFI Responses - - Summary (DRAFT)*. IVI RFI Handout, ITS America, Washington, DC, February 24, 1998.
17. R. Ferlis, *SFVR Overview, 2-16-99,* USDOT/National Highway Traffic Safety Administration, Washington, DC, February 99.
18. R. MacLennan, Paper No. 1015 Automated Highway System Technologies and Mass Transit. Fifth ITS World Congress. Date and venue unknown.
19. Transportation Cooperative Research Program, Research Results Digest. *Creating a New Future for Public Transportation: TCRP's Strategic Road Map*. Transportation Research Board, National Research Council, Washington, DC, April 1998.
20. Urban Institute. Cost of Highway Crashes, Final Report. June 1991.
21. U. S. Department of Defense. Military Standard: System Safety Program Requirements. MIL-STD-882-C.
22. U. S. Department of Transportation, Federal Highway Administration, *Truck and Bus Crash Factbook, 1993*. Washington, DC, October 1995.
23. U. S. Department of Transportation, Federal Highway Administration, *Truck and Bus Crash Factbook, 1994*. Washington, DC, October 1996.
24. U. S. Department of Transportation, Federal Highway Administration, *Truck and Bus Crash Factbook, 1995*. Washington, DC, September 1997.
25. U. S. Department of Transportation, Federal Highway Administration, Research and Development/Turner Fairbanks Research Center, *Opportunities for Advanced Vehicle Control Systems in Commercial Vehicle Operations and Public Transportation Systems.* FHWA-RD-96-139. McLean, VA, January 1997.
26. U. S. Department of Transportation, Federal Highway Administration, Joint Program Office for Intelligent Transportation Systems, *1996 Report to Congress.* Washington, DC, September 26, 1997.
27. U. S. Department of Transportation, Federal Transit Administration. *FTA Five-Year Research and Technology Plan*. FTA-MA-26-7037-98-01. June 1998.
28. U. S. Department of Transportation, Federal Transit Administration. *Safety Management Information Statistics (SAMIS), 1993 Annual Report*. FTA-MA-26-0009-95-3. May 1995.

29. U. S. Department of Transportation, Federal Transit Administration. *Safety Management Information Statistics (SAMIS), 1994 Annual Report*.

30. U. S. Department of Transportation, Federal Transit Administration. *Safety Management Information Statistics (SAMIS), 1995 Annual Report*. FTA-MA-26-9033-97-1. April 1997.

31. U. S. Department of Transportation, Federal Transit Administration. *Safety Management Information Statistics (SAMIS), 1996 Annual Report*. FTA-MA-26-9033-98-1. May 1998.

32. U. S. Department of Transportation, Federal Transit Administration. National Transit Summaries and Trends for the 1996 National Transit Database Report Year. January 1996.

33. U. S. Department of Transportation, Federal Transit Administration. *Transit Profiles for the 1996 National Transit Database Report Year*. January 1996.

34. U. S. Department of Transportation, Federal Transit Administration. *Transit Intelligent Vehicle Initiative (IVI) Forum and Roundtable, Houston, Texas, December 15, 1997*. DOT-VNTSC-FTA- 98-1. February1998.

35. U. S. Department of Transportation, Federal Transit Administration. Transit Intelligent Vehicle Initiative (IVI) Near Term Direction Meeting, Salt Lake City, Utah, February 36-27, 1998. November1998.

36. U.S. Department of Transportation, National Highway Traffic Safety Administration. *National Automotive Sampling System, General Estimates System, User's Manual*. 1996.

37. U. S. Department of Transportation, National Highway Traffic Safety Administration. *NHTSA Symposium on Rear-end Collision Avoidance*. The Johns Hopkins University, Applied Physics Laboratory, Laurel, MD, October 2, 1998.

38. U.S. Department of Transportation, National Highway Traffic Safety Administration. State Traffic Safety Information. Washington, DC, January 1, 1998.

39. U. S. Department of Transportation, National Highway Traffic Safety Administration. *Traffic Safety Facts, 1997*. Washington, DC, November 1998.

40. U. S. Department of Transportation, National Highway Traffic Safety Administration. *Traffic Safety Facts, 1996*. Washington, DC, December 1997.

41. U. S. Department of Transportation, National Highway Traffic Safety Administration. *Traffic Safety Facts, 1995*. Washington, DC, September 1996.

42. U. S. Department of Transportation, Office of the Secretary of Transportation. *Memorandum: Update of Value of Life and Injury for Use in Preparing Economic Evaluations*. Washington, DC, March 14, 1995.

43. U. S. Department of Transportation, Research and Special Programs Administration/Volpe National Transportation Systems Center. *Project Plan Agreement HS-816; Evaluation of Delco/GM Rear-End Countermeasures.* USDOT/Volpe Center, Cambridge, MA, September 1, 1998.

44. U. S. Department of Transportation, Research and Special Programs Administration/Volpe National Transportation Systems Center. *Project Plan Agreement HS-919; Developemnt of Collision Avoidance Data for Light Vehicles.* USDOT/Volpe Center, Cambridge, MA, March 1, 1999.

45. U. S. Department of Transportation, Research and Special Programs Administration/Volpe National Transportation Systems Center. *Project Plan Agreement HW-80Q; Benefit Assessment of Intelligent Vehicle Systems.* USDOT/Volpe Center, Cambridge, MA, September 17, 1998.

46. W.G. Najim, *Analysis of Transit and Intercity Bus/Van Crashes*. USDOT/Volpe Center, Cambridge, MA, February 18, 1998.